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ST. MARYS RIVER

SHORELINE EROSION AND SHORE STRUCTURE DAMAGE

1980-81 CLOSED NAVIGATION SEASON

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Extension of the navigation season beyond the traditional dates resulted in complaints of shoreline and dock damage along the navigation channels. Studies of shoreline erosion and structure damage due to navigation in ice along the St. Marys River were undertaken under the authority of the Great Lakes and St. Lawrence Seaway Navigation Season Extension Study. One of the problems in determining the relative importance of navigation in shoreline erosion and dock damage had been the lack of information on such damages during a navigation-free winter. After the year-round navigation under the Demonstration Program ended, limited navigation was planned during the 1979-80 and 1980-81 winter seasons; thus providing an opportunity to examine the St. Marys River under relatively undisturbed conditions. The data from the 1979-80 season was presented in a previous report. This report covers the 1980-81 limited navigation season.

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PREFACE

This report was prepared by James L. Wuebben, Research Hydraulic Engineer, Ice Engineering Research Branch, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by the Detroit District, U.S. Army Corps of Engineers.

Field information for the period of study was provided by John J. Gagnon, Engineering Aide, Ice Engineering Research Branch, Dr. George R. Alger, Water Resources Consultant (under contract).

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INTRODUCTION

During the period from 1961 to 1970, navigation on the St. Marys River closed for the winter between 14 December and 11 January and reopened between 1 and 17 April. Subsequent extension of the navigation season beyond the traditional dates resulted in complaints of shoreline and dock damage along the navigation channels. Under the general authority of the Great Lakes and St. Lawrence Seaway Navigation Season Extension Study (Public Law 91-611, Section 107(b)), studies of shoreline erosion and structure damage due to navigation in ice along the St. Marys River were undertaken.

During these studies one of the problems in determining the relative importance of navigation in shoreline erosion and dock damage has been the lack of information on such damages during a navigation-free winter. Since limited navigation was planned during the 1979-80 and 1980-81 winter seasons, it was felt that it would be an opportune time to examine the St. Marys River system under relatively undisturbed conditions. The results from the earlier season were presented previously in the report "St. Marys River Shoreline Erosion and Shore Structure Damage, 1980 Closed Navigation Season" (Wuebben, 1981). The present report covers the 1980-81 closed season.

The St. Marys River was ostensibly closed to navigation from 31 December 1980 to 24 March 1981. Actually there were 9 ship passages during early March. On 3 March four icebreakers (The Mackinaw, Westwind, Mobile Bay and Katmai Bay) and an oil tanker (The Amoco Wisconsin) sailed upriver to Soo Harbor, and all except the Katmai Bay returned the next day. There

was also limited navigation during the 1979-80 closed season icluding seven trips by the Katmai Bay and one by the Mackinaw.

BACKGROUND

There are several conceivable ways in which vessel passage might affect sediment transport and shore structures including ship wave action, propeller wash and other hydraulic effects. In addition, during navigation in ice, damage might occur due to the direct movement of ice in contact with vessels, by disruption of natural ice cover characteristics, and by interactions between ship-related water movements and the ice cover. The significance of these various effects depends on a number of local conditions such as the bathymetry, water levels, soil conditions, ice conditions, shore and shore structure composition and geometry, and the presence of other natural agents such as ambient water currents or waves.

As a starting point in discussing this past winters findings, it should be helpful to briefly discuss the effects of shipping determined from previous work. A more complete review may be found in last years report (Wuebben, 1981).

Ship Waves

Wave action is the mode of action normally associated with ship induced damages in the nearshore zone. When a ship sails in ice-free open water, a system of diverging and transverse waves develops. Diverging waves are those which form the familiar "V" shaped wave pattern associated with ship passage, while transverse waves form a less noticeable wave train which follows the vessel and are oriented normal to the sailing line.

Due to decay of the waves as they propagate and the interaction of these two dissimilar wave sets, the generated wave heights are a strong function of position. In deep water these waves form a constant pattern and meet to form a locus of cusps at an angle of about 19°28' to the sailing line. This angle becomes greater in shallow water.

The maximum wave height occurs at the locus of the cusps. The wave heights at this cusp locus decrease at a rate inversely proportional to about the cube root of the distance from the disturbance. This decay is caused primarily by the distribution of energy along the crest of the wave except in very shallow water (Sorenson, 1973).

The height of ship-generated waves is mainly a function of vessel speed (Gates and Herbich, 1977). Figure 1 below was developed by Ashton (1974) from data presented by Sorenson (1973) for waves generated by boats with displacements from 3 to 343 tons. These data were derived from measurements in the Oakland Estuary in a water depth of about 35 feet for various ship speeds. Noting that this figure ignores depth and draft effects, hull form and other parameters known to influence wave heights, there is remarkably little scatter. The figure serves to show the strong relation between wave height and ship velocity.

However, during winter ice conditions, these waves are effectively damped by the ice cover. Figure 2 shows the effect of increasing thicknesses of ice on the height of waves. Relative wave amplitude is defined as the height of a wave passing under ice divided by the height of that same wave under open water conditions. The wave period for ships on the St. Marys River is typically about 2 to 3 seconds. Thus according to

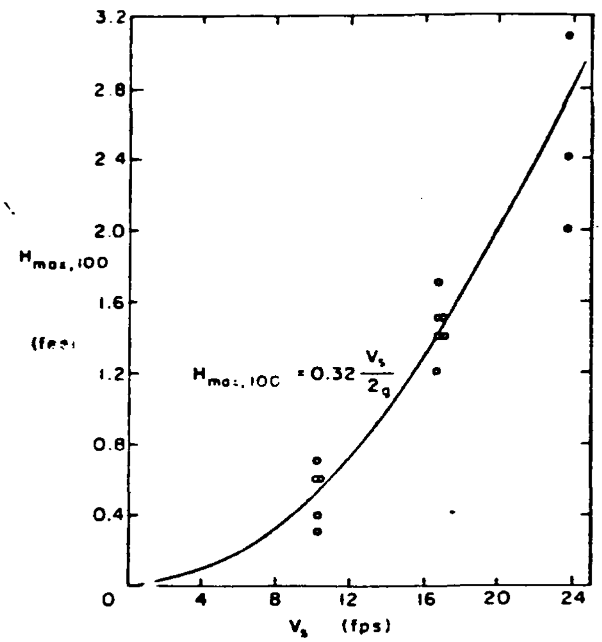

Figure 1. Maximum wave heights 100 feet from sailing line for variety of hull forms (after Ashton 1974).

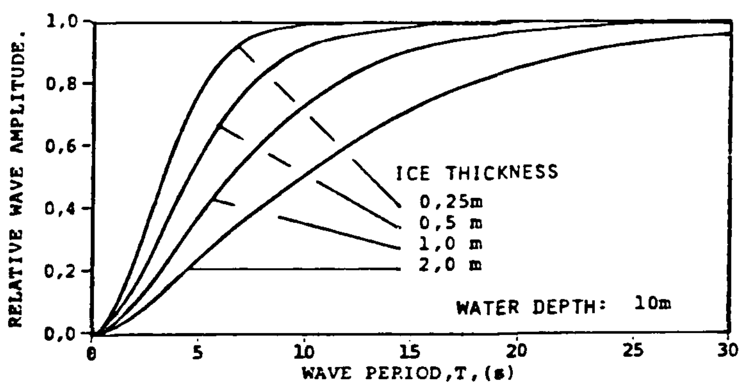

Figure 2. Damping of waves at ice edge (after Carter, et. al., 1981)

Figure 2, ship waves during navigation in ice should be quite small. In addition, since these waves decay rapidly (even in open water) as they propagage from the ship, these waves are considered to be insignificant.

Propeller Wash

During vessel passage the bottom and sides of a channel may be subjected to a propeller driven water jet. There has been very little study of sediment transport due to prop wash, and there was no data available for the areas considered in this report. This effect, however, is relatively localized within the navigation channel. Since this report deals only with damage in the nearshore zone, prop wash will not be considered further.

Hydraulic Effects of Ship Passage

Although ship waves and other hydrodynamic effects of vessel passage have been studied in terms of vessel maneuverability and power requirements, the effects of vessel passage are not yet understood in terms of natural flow patterns and distribution, and adverse environmental effects. Information for periods of ice cover is almost nonexistent.

When a vessel is in motion, even in deep water, the water level in the vicinity of the ship is lowered and the ship with it (vessel squat). For the same ship this effect increases as vessel speed increases or as water depth decreases. When a ship enters restricted water areas, there is a considerable change in flow patterns about the hull. The water passing beneath the hull must pass at a faster rate than in deep water, and as a result there is a pressure drop beneath the vessel which increases vessel squat. In a channel which is restricted laterally, this effect is further

exaggerated. A vessel in a laterally restricted channel may encounter a condition which tends to push the bow away from one side of the channel and draw the stern toward it. These effects can occur independently when a channel is restricted either laterally or vertically and unrestricted in the other direction.

There is, however, another problem associated with the water level drop caused by the presence and movement of a ship in restricted waters. This water level drop in the vicinity of the ship is in effect a trough which extends from the ship to the shore and which moves along the river or channel at the same velocity as the ship. As the ship's speed increases the moving trough deepens. The mechanics of this process have been described in last year report (Wuebben, 1981).

The phenomenon of nearshore drawdown and surge during vessel passage may be explained in terms of the moving trough. In sufficiently deep water, the moving trough appears as a fluctuation of the elevation of the water surface. To an observer in a shallow or nearshore area where the depressed water level approaches or reaches the river bed, it appears that the water level recedes from the shoreline as the ship passes and that this is followed by an uprush and finally a return to normal level after the vessel-induced surface wave are damped.

<u>Shore Damage</u>

The role of ice in sediment transport and shoreline erosion has many facets. The most obvious effect is that ice formed on a shore or riverbank may isolate and thereby protect the shore. Ice formations can, however, cause significant localized damage by gouging ordinarily stable beach or

bank formations, removing protective vegetation, by adfreezing sediment at the ice-soil interface, and by entrainment of sediment within the ice structure.

Shore damage due to the lateral movement of ice induced by vessel passage is ordinarily small, limited to early or unstable ice conditions, and shore areas in close proximity to the navigation track. During spring break-up larger, more massive ice floes may act upon a shore, but with warmer temperatures the ice is usually deteriorated and weaker.

Shore damage due to the horizontal movement of ice, while possibly significant, is unpredictable, infrequent, and difficult to quantify. A long length of shoreline may be affected over a period of years, but only a small portion of such a reach might be affected in any one year. As a result, structural shore protection would be difficult to apply and most likely uneconomical. The regulation of vessel traffic in affected areas during certain ice conditions periods may provide the best means of damage mitigation.

Another consideration is the effect of ice on the general hydraulics of a system. In a river, the presence of an ice cover changes the open channel conditions into a form of closed conduit flow with resultant changes in velocity profiles and distribution. The added boundary shear due to the ice cover will decrease flow velocities and increase flow depth. Although there may be anomolies, in general the presence of an ice cover will tend to reduce sediment discharge. The presence of ice jams, frazil dams or other ice irregularities causing a constriction or deflection of flow may result in damage.

In order for sediment transport to occur without direct ice action near bottom water velocities sufficient to overcome a sediment particle's resistance to motion must exist. These water velocities may be due to ambient river conditions, wind driven waves, general turbulence, or ship-induced effects among others, and might be enhanced by channel configuration or ice irregularities. During vessel passage large rapid changes in river velocity magnitude and direction can occur.

Three modes of transport of granular bottom sediments have been observed during both ice-covered and ice-free conditions (Wuebben et al. 1978). They are bedload, which is typified by a pattern of slowly migrating sand ripples on a river bed; saltation load, the movement of individual sand grains in a series of small arcs beginning and ending at the river bed; and a process which will simply be called explosive liquefaction.

In addition to these alterations in water flow velocity, the changes in water surface elevation during ship passage can occur more quickly than the pore pressure in the soil comprising the river bed can adjust. If the decreased water pressure on the river bed during the passage of the moving trough occurs faster than the change in soil pore pressure, a net uplift force on the soil near the surface may occur. After the trough passes and the water level rises the process is reversed and there is a net downward force on the river bed sediment. As the ship passage cycle is repeated this mechanism, in conjunction with gravity acting downslope, would tend to encourage a net offshore migration of sediment in addition to any transport due to water velocities alone.

During winter ice conditions, the passage of the moving trough can cause the grounding of an ice cover in shallow water and nearshore areas, and nearshore cracks in the ice may develop running roughly parallel to the water depth contours. With recurring moderate water level fluctuations, these hinge cracks do not completely refreeze and can provide an ice-movement relief mechanism. Continuing vertical and horizontal moveme of the ice cover may cause the accumulation of ice debris (which resembles pressure ridges) at these active cracks.

The mechanisms described above may have effects beyond shoreline erosion. Large areas of grounded ice, which result from the packing of brash ice under the ice cover, or increased frazil production because of increased open water areas may have an impact on benthic environments and may transmit ship induced vibrations to the shore and shore structures. The reported effects of these vibrations range from aesthetically disturbing to structurally damaging.

In wetlands or shallow areas, damage may occur even though erosion is negligible. In shallow water, ship-induced velocity and water level changes be large, possible disrupting vegetation by water and ice movement. An ice cover might even ground and directly strike the bed during vessel passage. Rapid water pressure changes might also be significant.

When a large enough, ship-induced moving trough passes through a shallow water area, the movement of bottom sediment may disrupt benthic environments, and the translatory movement of the water has been observed to cause water, sediment, vegetation, and even small fish to be sprayed up through the cracks and onto the ice. During a specific vessel passage,

about a dozen fish of various species, ranging in size up to about 6 inches in length, were washed through a nearshore crack and onto the ice. It is possible that other, smaller organisms went unnoticed.

Shore Structure Damage

Damage might be considered to occur due to water currents, water level fluctuations, and the movement of ice. Structural damage due to ship-induced water currents is considered insignificant for existing conditions along the St. Marys River.

Structural damage due to ship-induced waves is possible. However, under existing conditions this damage mechanism is typically caused by and limited to excessive vessel speed. If sound speed limits are enforced, damage to shore structures due to waves should be minimal.

The major potential damage mechanism is ship-induced drawdown, particularly drawdown during periods of ice cover.

Ice effects on structures typically fall into one of the following categories:

1) Static Ice Forces - These forces arise from an ice sheet in contact with a structure subject to thermal expansion and contraction or subject to steady wind or water drag forces.

2) Dynamic Ice Forces - These forces arise from ice sheets or floes which move against a structure due to water currents or wind.

3) Vertical Ice Forces - These forces arise due to a change in water level and require the adhesion of floating ice to structures.

For small structures in a river situation the dynamic horizontal and vertical ice forces are typically the critical modes of ice action.

Horizontal Ice Forces: Depending on the size and strength of an ice floe, the horizontal force exerted on a structure may be dependent on the strength of the ice sheet and its failure mode (bending, crushing or shear) or by the magnitude of the force driving the ice sheet (wind or water current). With a vertical pile or structure face, failure of the ice sheet usually occurs by crushing. Current American Association of State Highway and Transportation Officials (AASHTO) standards employ a standard crushing strength for ice of 400 psi while the current Canadian bridge design code provides the "effective ice strength" values ranging from 100 to 400 psi. Thus if there is sufficient driving force for the ice sheet, a pile may be subjected to large horizontal ice loads.

Typically ships do not directly transfer forces to a structure through the ice unless the ships come very close to shore. Rather they may break up or dislodge ice allowing it to be moved by natural wind, waves or water currents against a structure. Damage due to horizontal forces can occur naturally during the unstable early ice period or during spring breakup. Typically, during the mid-winter period on the St. Marys the ice is thick, and completely covers the water in most areas of the St. Marys River so that little horizontal movement takes place. With winter navigation, however, there can be small, incremental movement of large ice masses.

With the passage of a ship the resultant drawdown tends to draw water in the offshore direction. This also pulls the ice cover slightly toward the channel. The following rise in water levels does not completely close the crack, and there can be some freezing of new ice in the crack. With repeated cycles, this mechanism can incrementally jack the ice cover hori-

zontally toward the channel. If any cracks pass through a structure they can be pulled offshore as well. This has occurred so severely near Johnsons Point on the St. Marys River in the past that the owner of one dock structure has resorted to using wire rope cables to help protect his structures from being pulled offshore.

Vertical Ice Forces: A major source of damage is the vertical movement of an ice sheet. On any large body of water the water level is constantly fluctuating. Coastal variations are primarily due to tidal action, while on large lakes barometric pressure fluctuations, wind set up, runoff and seiche action contribute. During periods of open water, the normal fluctuations are relatively harmless. In conjunction with an ice sheet that is firmly attached to marine structures, these fluctuations can exert large vertical forces through the floating ice cover.

Typically the structures that suffer the most damage are light duty, pile supported piers such as those constructed for pleasure boaters. Designed for summer activity, the support piles have very little skin resistance to an upward force. With a rise in water level, the buoyant ice sheet lifts the pile from the soil and the void under the bottom tip of the pile fills in. When the water level again drops, the weight of the ice is supported by the skin friction and point bearing of the pile. Since the pile is not driven into the soil as easily as it is pulled out, if the water level continues to drop, the ice will eventually break and the ice sheet will drop relative to the pile. The ice may then refreeze to the pile but at a lower position now that the pile has been lifted. This process then can be repeated in cycles throughout the winter, gradually "jacking" the pile completely out the soil.

Typically for a pile when the temperature is below freezing the ice will adhere to a pile and break at some small distance away. When temperatures are above freezing the ice may slip along a pile surface and even abrade the pile surface. Another problem that may occur is when the water level is high enough so that the surface of the ice is in contact with the cross members of the dock. Under this condition the ice forces may now act directly on the structure.

With moderate water level fluctuations and sufficient cycle frequency, the crack in the ice sheet may not refreeze and a permanent open or "active crack" may result. This may serve as a force release mechanism. If the crack passes through a dock, if ships pass infrequently so that the cracks may refreeze, or if the fluctuations are larger this protective mechanism is lost.

If piles resist uplifting, they may generate a pile of ice rubble about them from the continuing water level fluctuations causing breaking of the ice about the pile. These rubble piles have been observed to develop to the point where they contact the horizontal members of a dock and cause damage.

Damage Criteria

The objective of this study is to examine the change in incidence of damage to shorelines or shore structures due to winter navigation. A detailed analysis in which ship induced forces are compared with the stability and strength characteristics of each individual structure or shore area could lead to a prediction of damages for anticipated on site conditions. However, the field data necessary for such an analysis is not

available in sufficient detail and our predictive capability is not refined enough to conduct such an analysis over such a wide area.

Instead our analysis centered on areas in which ship effects are considered to be great enough to have a potential for damage, and examining conditions with and without navigation in ice. Selection of areas potentially affected by vessel passage was based on prior field experience, an analytical prediction of ship effects, and other available documentation.

A major problem in such analysis is in defining the magnitude of ship induced effects to be considered unacceptable. In the case of sediment transport we cannot realistically require that ships cause no sediment motion, even if we could predict the transient, ship-induced threshold of motion in the large irregular channels under consideration. Small sediment dislocations should not necessarily be considered damage, particularly since natural currents, waves or recreational boating or other factors may be much more significant.

In addition, large scale navigation already exists and the traditional navigation season extends into periods of substantial ice cover. A significant portion of ship and ice related damage may occur during the fall ice formation period or spring breakup. This requires a distinction between traditional and extended season navigation effects that is difficult to obtain. For example, if a pile has been jacked vertically one foot due to ship and ice action late in the traditional season, should an additional inch of jacking during an extended season be termed significant damage?

The definition of damage due to winter navigation is further complicated since the magnitude of ship induced effects is heavily influenced by vessel speed and water levels which are particularly significant since they are variable and beyond control for the purpose of this study. In most cases envisioned, properly designed speed limits, if observed, would eliminate damage due to vessel passage. There are some potential problems in certain cases, however, in allowing ships sufficient power to maintain control and there is some question about penalizing smaller vessels by requiring them to travel at a lower velocity based on the requirements of larger ships.

Water levels present another factor beyond the scope of vessel effects alone, and yet a very important consideration. As shown in Figure 3 for a shore profile on the St. Marys River, during a high water period both natural and ship induced forces are free to act directly on the low bluff at the waters edge. This bluff is frequently considered to be the "shoreline" by many property owners. If the water level was lower, the water would not act directly against this "shore." Persistent erosive forces might eventually erode the waters edge back to the bluff locations, but in the interim the rate of material loss would be less since the mild slope would dissipate energy more efficiently and sloughing of the bluff would not occur.

For the case of structural damage water levels are not as significant unless the level is high enough so that ice may act directly on horizontal members. But we do have another problem. Data during ice conditions has been largely limited to dealing with gradual water level fluctuations and

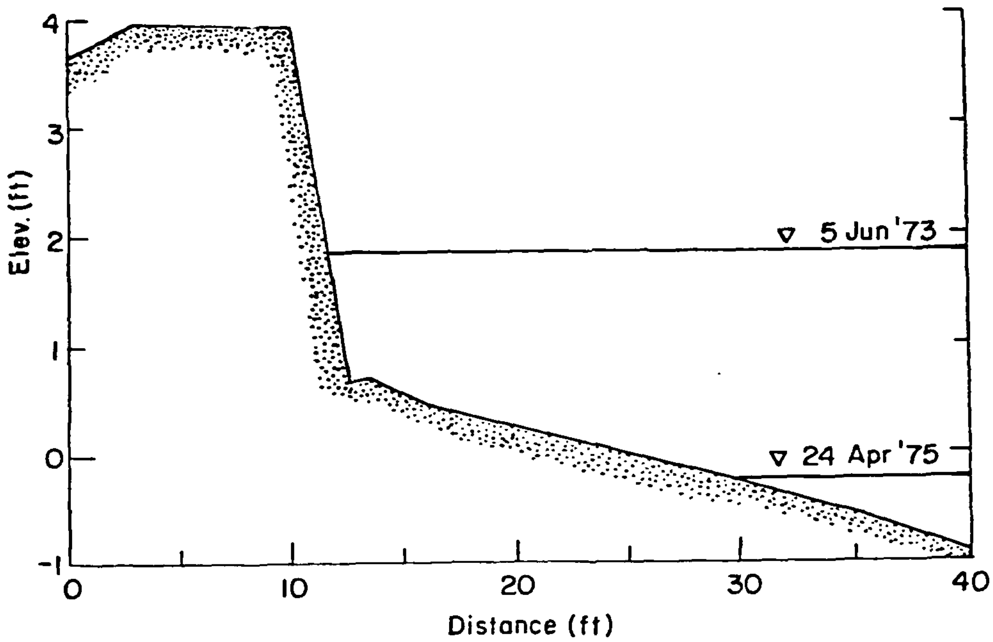

Figure 3. Relation of water level to shore profile.

estimates of horizontal forces. Ship induced forces due to ice are largely unknown. Very small water level fluctuations applied gradually may cause damage while a transient fluctuation of the same magnitude may pass faster than the structure may respond. As a result criteria for damage to small structures though based on experience, is still an estimate.

OBSERVATIONS DURING THE 1980 CLOSED SEASON

The shoreline and shore structures along the St. Marys River were monitored for ice-related damage during the closed navigation season of 1980-81. This period extended from 31 December 1980 to 24 march 1981, with only nine recorded vessel passages. On 3 march 1981, four U.S. Coast Guard icebreakers (The Mackinaw, Westwind, Mobile Bay, and Katmai Bay) and an oil tanker (The Amoco Wisconsin) sailed up from Lake Huron to Soo Harbor. All except the Katmai Bay made the return trip the following day. The closed season of the previous year extended from 15 January to 24 March 1980 with the only recorded vessel activity being seven trips by the USCG Katmai Bay and one trip by the USCG Mackinaw.

Sediment Transport and Shoreline Erosion

Various field measurements have been made by CRREL at sites along the St. Marys River since 1976, and previous work was conducted by the Detroit District beginning in 1972. For the past two winter field seasons three of these previously monitored sites were selected for further study during the closed navigation periods. These sites are shown in Figure 4 and are referred to as the Sugar Island Site, the Adams Site and the Nine Mile Point Site. Field information on shore damage was developed by a local consultant (Alger 1980, 1981). At each site, base and range lines had

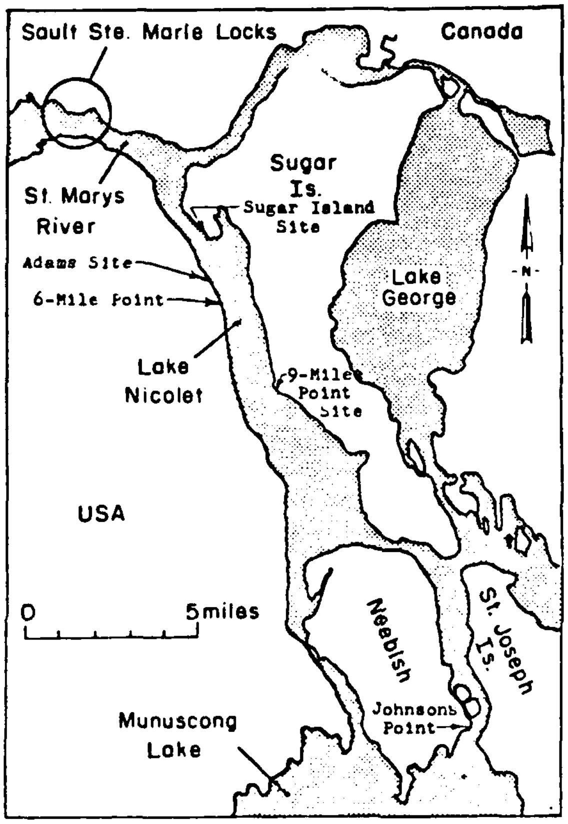

Figure 4. The St. Marys River.

previously been established and were presented in last years report (Wuebben, 1981). Range lines extend from points on the baselines and extend normal to the baseline out into the river. All measurements were taken along these range lines.

A field data collection program was developed based on experience gained from work during previous winter navigation seasons. From past experience it was determined that measurements should include ice thickness profiles, river bottom profiles and locations and patterns of active cracks.

During periods of ice cover, holes were drilled through the ice at selected locations along several range lines and ice thickness and river bottom elevation were measured at these known locations. Any visible crack patterns were also noted during the periods of field measurements. River bottom elevations were determined by wading the range lines using conventional survey equipment after the spring breakup.

Ice Thickness Profiles and Active Cracks. Ice thickness measurements at the three sites are reported in Tables 1 through 8. The profiles were continued along the various ranges until it was considered to be unsafe for personnel to move further offshore, or to the point where brash accumulations prevented reasonable measurements. The crack patterns show how the ice reacts to ship passage or water level fluctuations, and also indicate the normal locations of differential ice motion. That is, instead of the ice moving vertically or horizontally as a continuous sheet, these cracks allow the ice cover to behave as separate plates.

TABLE 1. Ice Thickness and Crack Patterns at Adams Site

RANGE B

DATE	2/5/81	2/26/81	3/26/81
Distance (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)
100	0.9	1.0	Fast grounded
150	1.3	1.1	shore ice to
160	1.3	1.3	a distance of
180	1.3	1.2	30 feet
200	1.3	1.2	shore.
220	1.3	1.3	No evidence
240	1.3	1.3	of vessel dis-
260	1.2	1.3	turbance.
270	1.3	1.2	No active shore
280	1.3	1.1	crack.
290	1.2	1.1	
300	1.2	1.2	
320	1.4	1.3	
340	1.4	1.3	
360	*	1.9	
380	1.3	0.9	
400	1.3	1.3	

* 1.4 - 1.8 feet (submerged brash)

(NOTE) No active parallel shore cracks - 5 inches snow on ice (2/5/81)
Much brash in track (2/5/81 and 2/26/81)

TABLE 2. Ice Thickness and Crack Pattern at Adams Site

RANGE E

DATE	2/5/81	2/26/81	3/28/81
Distance (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)
200	1.2	1.3	Same as 'B'
250	1.1	1.1	
300	1.7	1.7	
310	1.5	1.5	
320	1.4	1.4	
330	1.2	1.2	
340	1.[illegible]	1.2	
350	1.2	1.3	
400	*	1.3	
450	*	1.2	

* Submerged brash (depth indeterminant)

(NOTE) Same as 'B'

TABLE 3. Ice Thickness and Crack Patterns at Adams Site.

Range J

DATE	2/5/81	2/26/81	3/28/81
Distance (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)
200	1.4	1.3	Same as 'B'
250	1.3	1.1	
300	1.3	1.2	
320	1.5	1.4	
340	1.3	1.3	
360	1.8	1.6	
380	*1.8+	1.7	
400	1.5	1.5	
450	*3.0+	*1.7	

* Submerged brash

(NOTE) Same as 'B'

TABLE 4. Ice Thickness and Crack Patterns at Sugar Island Site.

Range O

DATE	2/5/81	2/26/81	3/28/81
Distance (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)
100	1.3	no	no
200	1.3	ice	ice
250	1.2		
300	1.9		
320	1.3		
340	1.3		
360	1.0		
380	1.1		
400	1.3		

(NOTE) 5 inches of snow on ice (2/5/81) - no active cracks - brach on track (2/5/81)
- some slush on ice (2/5/81)

TABLE 5. Ice Thickness and Crack Patterns at Sugar Island Site.

RANGE 7

DATE	2/5/81	2/26/81	3/26/81
Distance (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)
100	1.1	no	no
200	0.9	ice	ice
250	0.9		
300	0.9		
350	0.8		
400	0.8		

(NOTE) Same as 0

TABLE 6. Ice Thickness and Crack Patterns at Sugar Island Site.

RANGE 15

DATE	2/5/81	2/26/81	3/28/81
Distance (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)
100	1.1	no	no
200	1.0	ice	ice
250	0.9		
300	0.9		
350	0.9		
400	1.1		

(NOTE) Same as 0

TABLE 7. Ice Thickness and Crack Patterns at Nine Mile Site.

RANGE 2

DATE	2/6/81	2/26/81	3/26/81
Distance (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)
100	1.2	1.0	Fast grounded
200	1.6	1.5	shore ice to
300	1.2	1.3	a distance of
400	1.3	1.4	100 feet off-
500	1.0	1.0	shore.
560	1.2	1.2	No evidence of
580	1.3	1.3	vessel distur-
			bance.
			No active
			shore crack.

(NOTE) 10 inches snow on ice (2/6/81) - some snow ice (2/26/81) - no active cracks

TABLE 8. Ice Thickness and Crack Patterns at Nine Mile Site.

RANGE 7

DATE	2/6/81	2/26/81	3/26/81
Distance (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)	Ice Thickness (ft.)
100	1.4	—	Same as 2
150	1.4	1.7	
200	1.8	2.0	
220	2.0	1.8	
240	1.3	1.5	
260	1.3	1.4	
280	1.6	1.6	
300	1.4	1.6	
370	1.6	1.7	

(NOTE) Same as 2

In general ice thickness tended to be somewhat greater during the 1980-81 season than that reported during the 1979-80 season. Also, there was some navigation in ice prior to the close of navigation as well as the ship passages in early March mentioned earlier. This caused some ice disruption in mid-channel and large brash accumulations were evident.

As noted within the tables presenting ice thickness measurements there were no active cracks noted at any of the sites at the times when measurements were taken. Such active cracks were commonly reported at all sites during previous years with winter navigation. During the closed navigation season of 1979-80, there were no active cracks noted at the Adams Site, only a grounded shore crack at the Sugar Island Site. At the Nine Mile Site there was an active crack evident at the end of January, but not at other times. The lack of active cracks would indicate that water level fluctuations were small or infrequent during the period of study.

Offshore Bottom Profiles

Offshore bottom profiles were obtained at the locations indicated in Tables 1 through 8 for the ice thickness measurements. The results of these measurements are shown in Tables 9 through 16. The tables show elevations determined at all ranges for the two 1981 winter study periods as well as the elevations measured during the 1980 winter study period. The tables for the Sugar Island Site only show one date for 1981 measurements as no ice was present during the second study period. The ranges at the Sugar Island Site were also carried further into the offshore region in 1981 due to better and safer ice conditions relative to the 1980 period.

TABLE 9. Bottom Elevations at Adams Site.

RANGE B

DATE	1/31/80	2/5/81	2/26/81
Distance (ft.)	Elevation (ft.)	Elevation (ft.)	Elevation (ft.)
100	93.5	93.5	93.4
150	92.3	92.4	92.4
160	92.0	92.0	92.0
180	91.4	91.3	91.3
200	90.9	90.9	90.9
220	90.3	90.1	90.1
240	89.2	89.0	89.0
260	88.6	88.5	88.6
270	88.6	88.2	88.4
280	89.1	88.9	86.9
290	88.5	88.4	88.4
300	89.5	88.4	88.4
320	88.3	88.3	88.4
340	85.9	87.0	86.9
360	87.0	86.9	86.9
380	86.4	86.4	86.5
400	—	86.2	86.2

TABLE 10. Bottom Elevations at Adams Site.

RANGE E

DATE	1/31/80	2/5/81	2/26/81
Distance (ft.)	Elevation (ft.)	Elevation (ft.)	Elevation (ft).
200	90.6	90.5	90.6
250	89.9	89.8	89.9
300	88.9	88.8	88.9
310	89.0	88.7	88.6
320	89.3	89.0	89.0
330	88.4	87.9	87.9
340	87.2	87.0	87.1
350	86.8	86.6	86.7
400	85.6	—	85.5
450	86.1	85.9	85.9
500	85.6		

TABLE 11. Bottom Elevations at Adams Site.

RANGE J

DATE	1/31/80	2/5/81	2/26/81
Distance (ft.)	Elevation (ft.)	Elevation (ft.)	Elevation (ft.)
200	90.9	90.8	90.9
250	90.5	90.5	90.4
300	89.7	89.5	89.6
320	89.3	89.2	89.3
340	89.5	89.2	89.2
360	88.5	88.5	88.5
380	87.8	87.9	87.9
400	87.3	87.0	87.1
450	87.1	—	86.8

TABLE 12. Bottom Elevations at Sugar Island Site.

RANGE O

DATE	2/1/80	2/5/81
Distance (ft.)	Elevation (ft.)	Elevation (ft.)
100	93.4	93.4
200	93.2	93.1
250	92.9	92.8
300	92.2	92.1
320	91.3	91.2
340	88.8	88.7
360	88.5	88.3
380	85.6	85.1
400	88.2	87.8

TABLE 13. Bottom Elevations at Sugar Island Site.

RANGE 7

DATE	2/1/80	2/5/81
Distance (ft.)	Elevation (ft.)	Elevation (ft.)
100	93.7	93.6
150	93.4	—
200	93.2	93.0
220	93.2	—
240	93.2	—
250	—	92.9
300	—	92.0
350	—	91.2
400	—	88.7

TABLE 14. Bottom Elevations at Sugar Island Site.

RANGE 15

DATE	2/1/80	2/5/81
Distance (ft.)	Elevation (ft.)	Elevation (ft.)
100	94.3	94.3
120	94.0	—
140	93.2	—
160	93.6	—
200	—	93.6
250	—	93.5
300	—	92.3
350	—	93.3
400	—	92.0

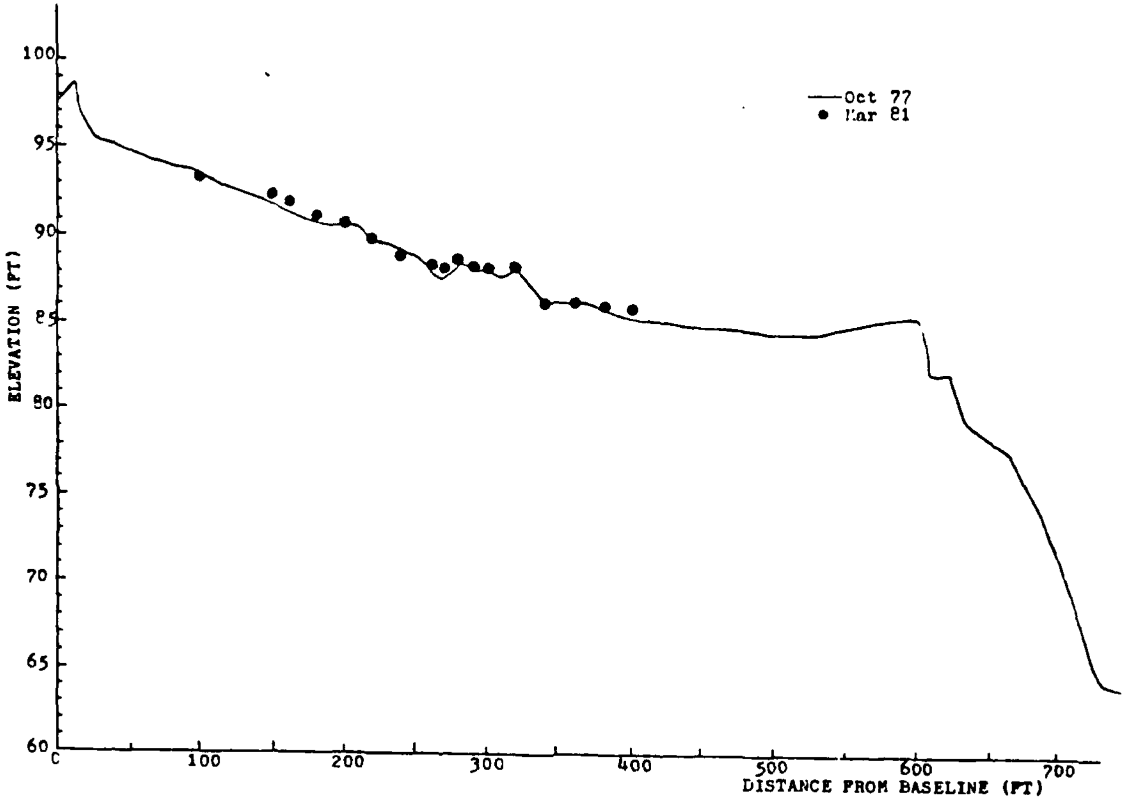

Figure 5. Adams Site Range B Offshore Profiles.

The data for offshore bottom profiles from the last field period with ice present were also plotted against previously obtained profiles from 1977. These profile comparisons are shown in Figures 5 through 12.

In general the data suggests little change and, as was reported in the August 1980 report, it compares well with similar information supplied since 1977 for the three sites. One noted exception would be the nearshore area at the Nine Mile Site which appears to have experienced some filling. This may be from erosion of the bluff and shoreline.

Near Shore Bank and Bottom Profiles. These profiles were measured in May of 1980 and 1981 wading using conventional survey equipment. The profiles were measured along all ranges at each of the three sites.

The profiles measured at the Adams Site were compared with profiles reported in the earlier studies. Previous reports indicated some changes at Ranges I, J, and K due to local construction. The measurements made during the last two seasons showed no further alteration of these three profiles nor any changes in any of the other range profiles. It would appear considering the history of these measurments that no serious erosion is now occurring at this site.

Nearshore profiles at the Sugar Island Site are reported in Figures 13 through 24 for ranges where change was evident. Bank and bluff recession is evident at some range locations. This site has been active in the past periods of study which might have led to suspicions of the effects due to winter navigation, however, these nearshore alterations appear to continue during a period with essentially no winter navigation.

TABLE 15. Bottom Elevations at Nine Mile Site.

RANGE 2

DATE	1/31/80	2/6/81	2/26/81
Distance (ft.)	Elevation (ft.)	Elevation (ft.)	Elevation (ft.)
100	91.1	91.4	91.2
200	89.6	90.1	90.0
300	89.2	89.8	89.7
400	88.9	89.1	89.0
500	88.9	89.1	89.0
560	87.0	86.5	86.3
580	76.7	75.4	75.3

TABLE 16. Bottom Elevaions at Nine Mile Site.

RANGE 7

DATE	1/31/80	2/6/81	2/26/81
Distance (ft.)	Elevation (ft.)	Elevation (ft.)	Elevation (ft.)
100	90.8	91.4	—
150	88.9	89.3	89.2
200	87.8	87.9	87.8
220	87.5	87.6	87.6
240	87.1	87.2	87.2
260	87.1	87.4	87.3
280	87.0	87.3	87.2
300	87.1	87.3	87.2
370	83.6	83.9	83.6

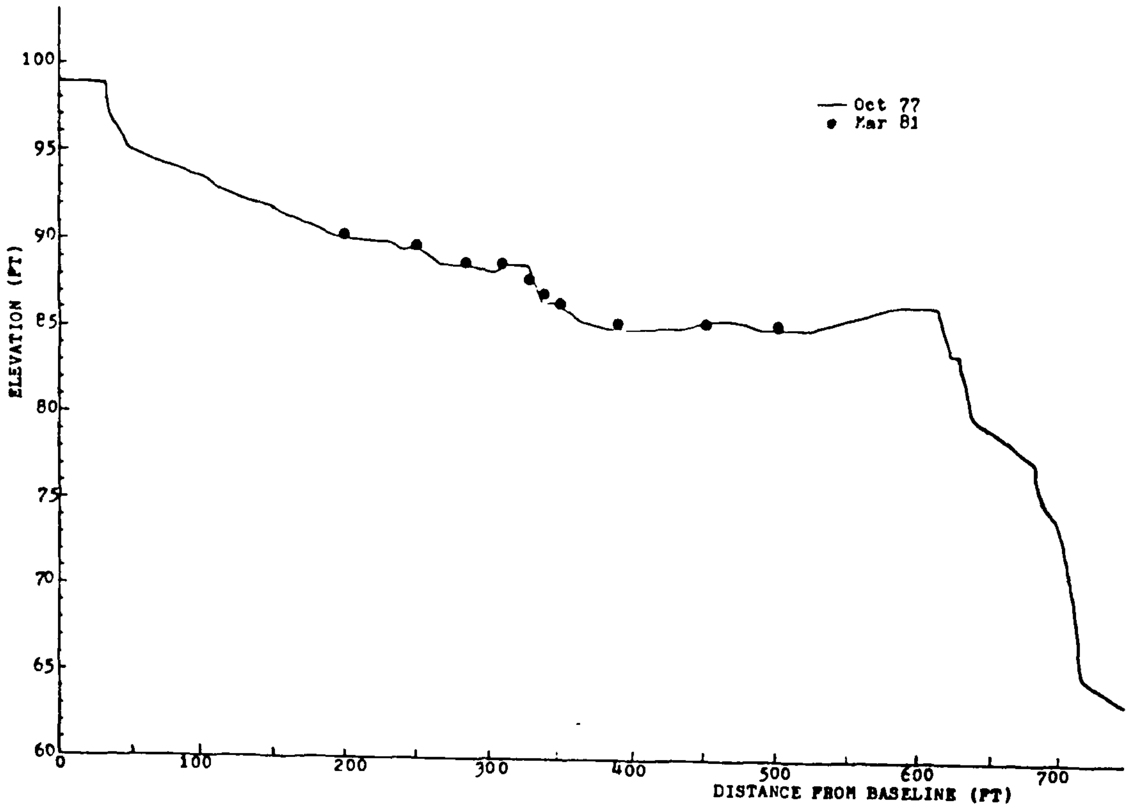

Figure 6. Adams Site Range E Offshore Profiles.

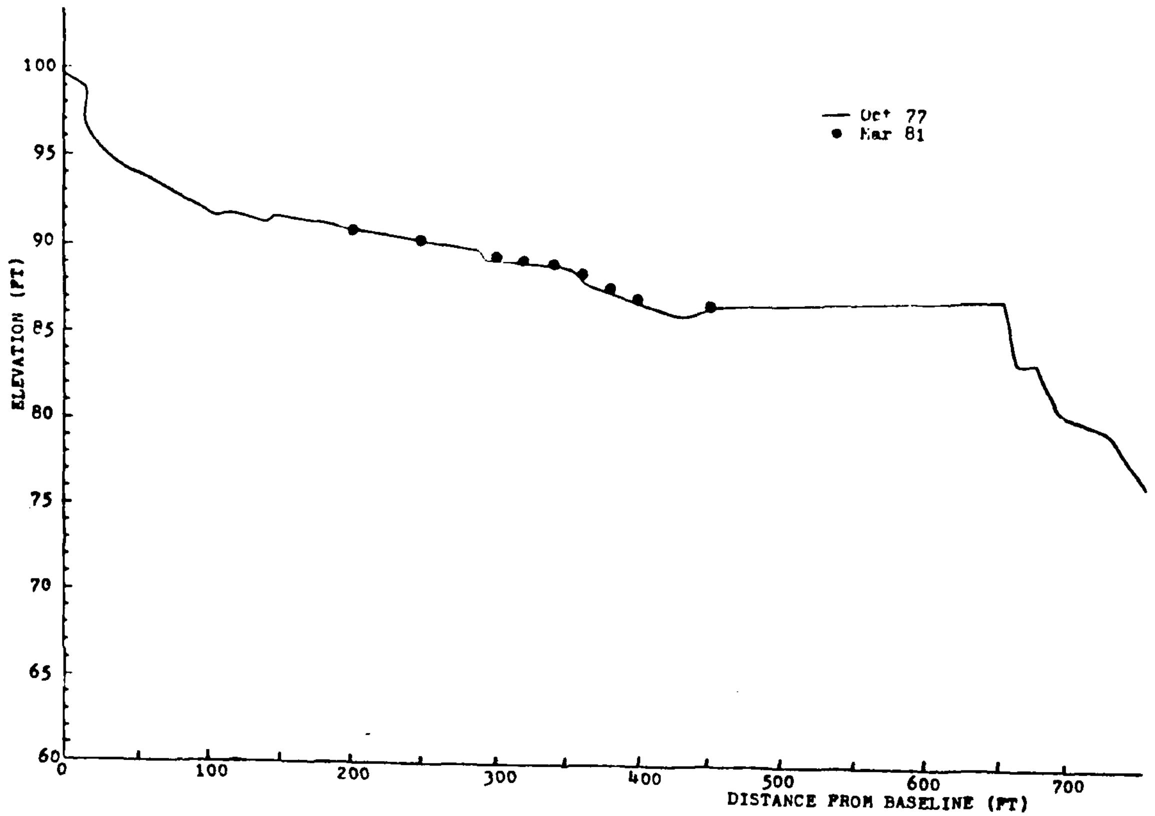

Figure 7. Adams Site Range J Offshore Profiles.

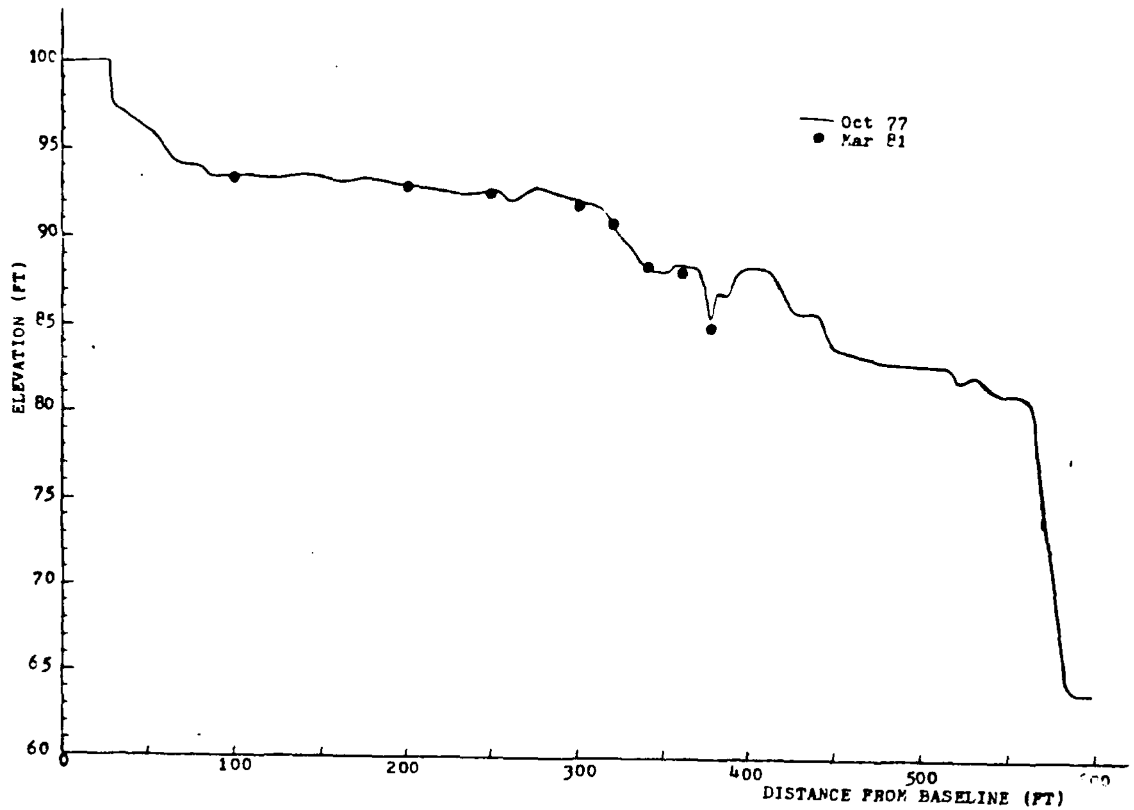

Figure 8. Sugar Island Range 0 Offshore Profiles.

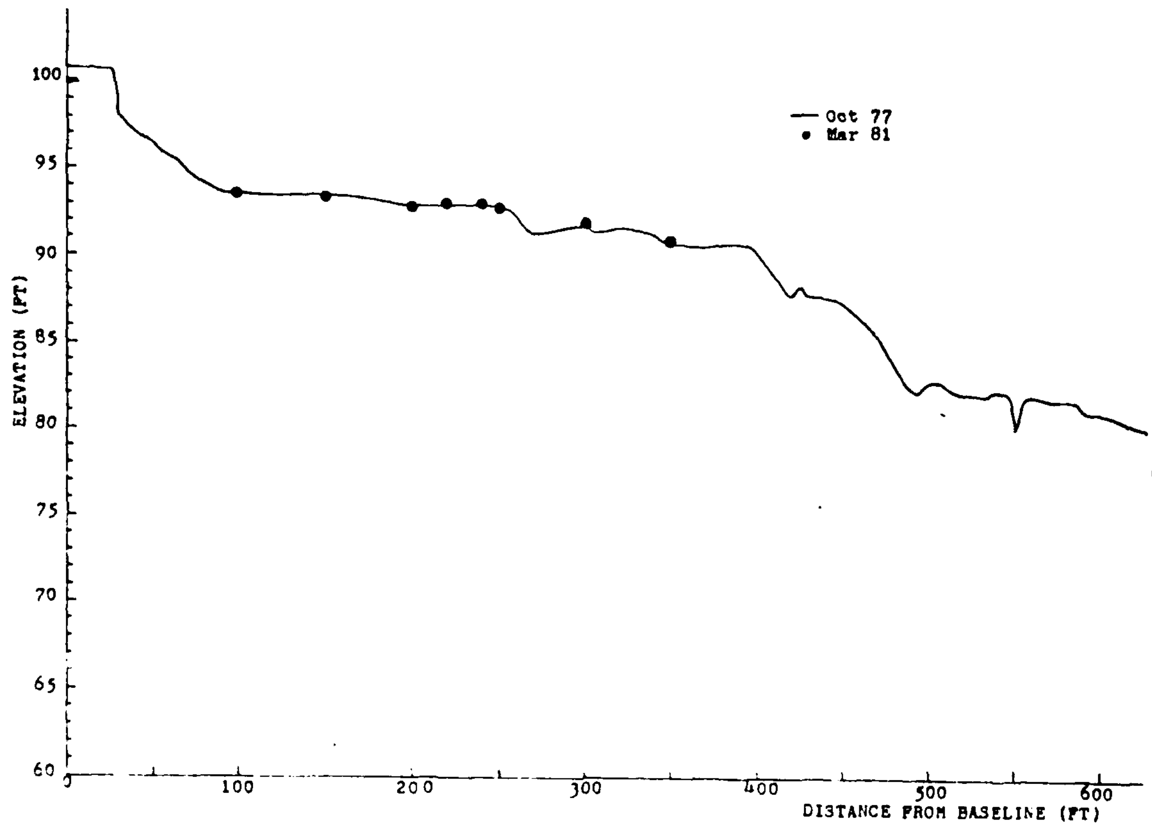

Figure 9. Sugar Island Range 7 Offshore Profiles.

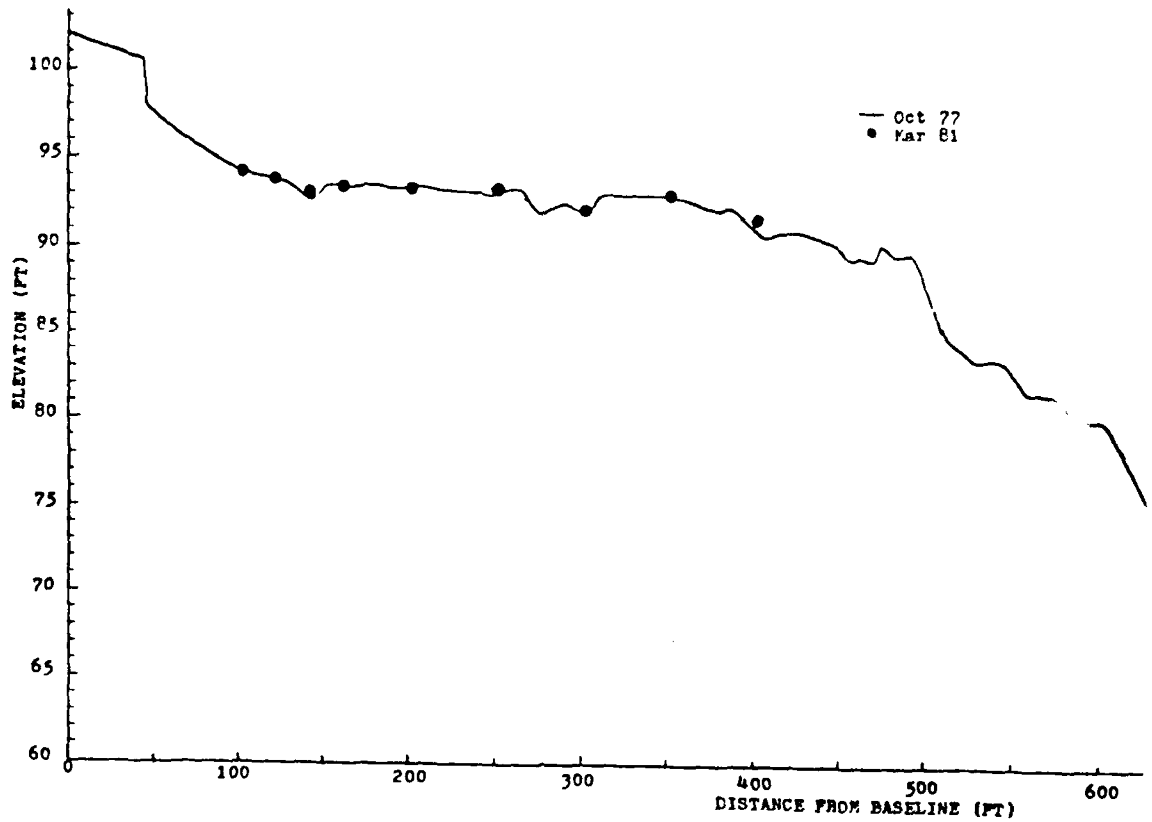

Figure 10. Sugar Island Site Range 15 Offshore Profiles.

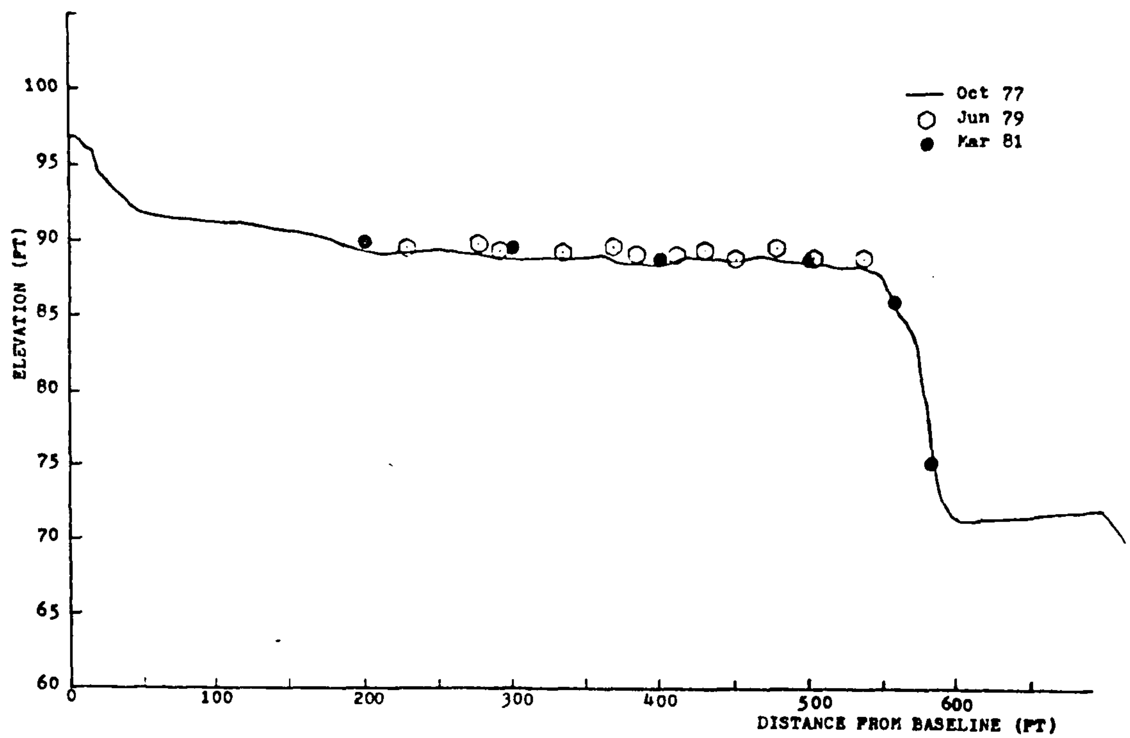

Figure 11. Nine Mile Site Range 2 Offshore Profiles.

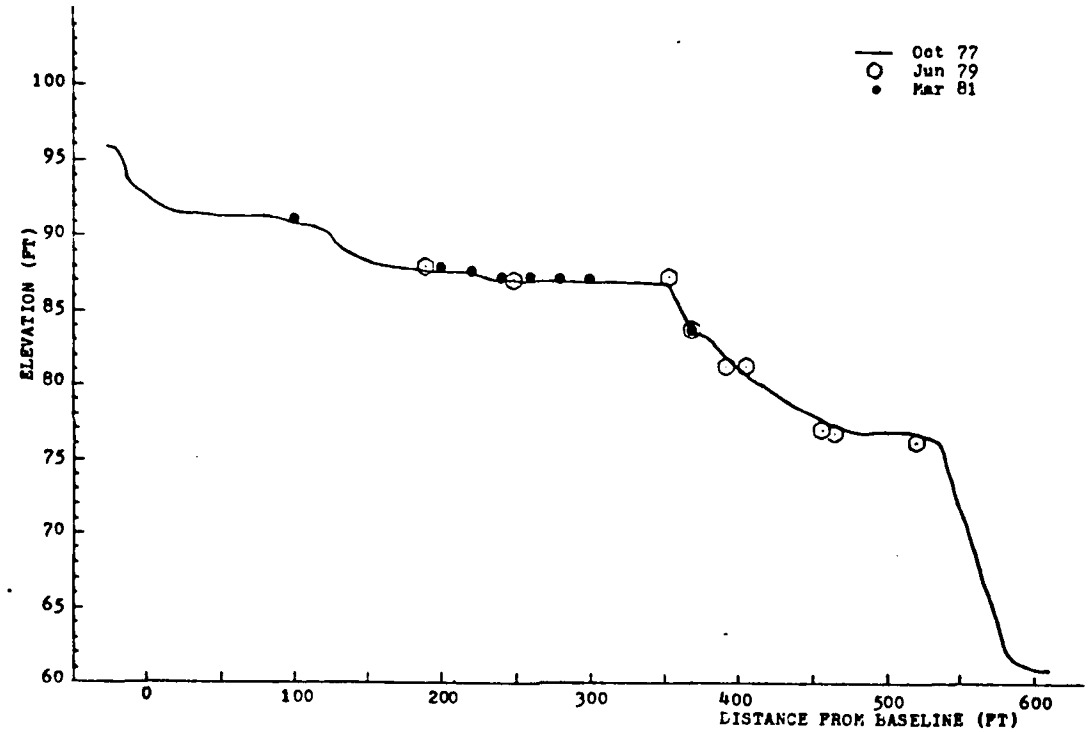

Figure 12. Nine Mile Site Range 7 Offshore Profiles.

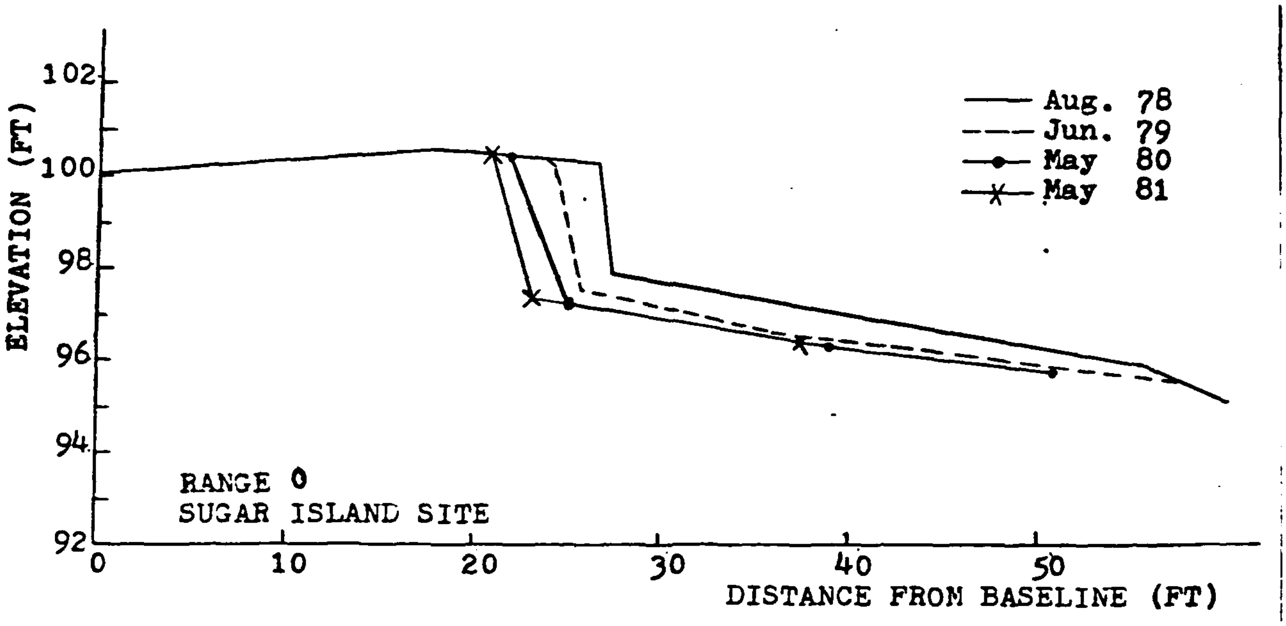

Figure 13. Range 0 Profiles.

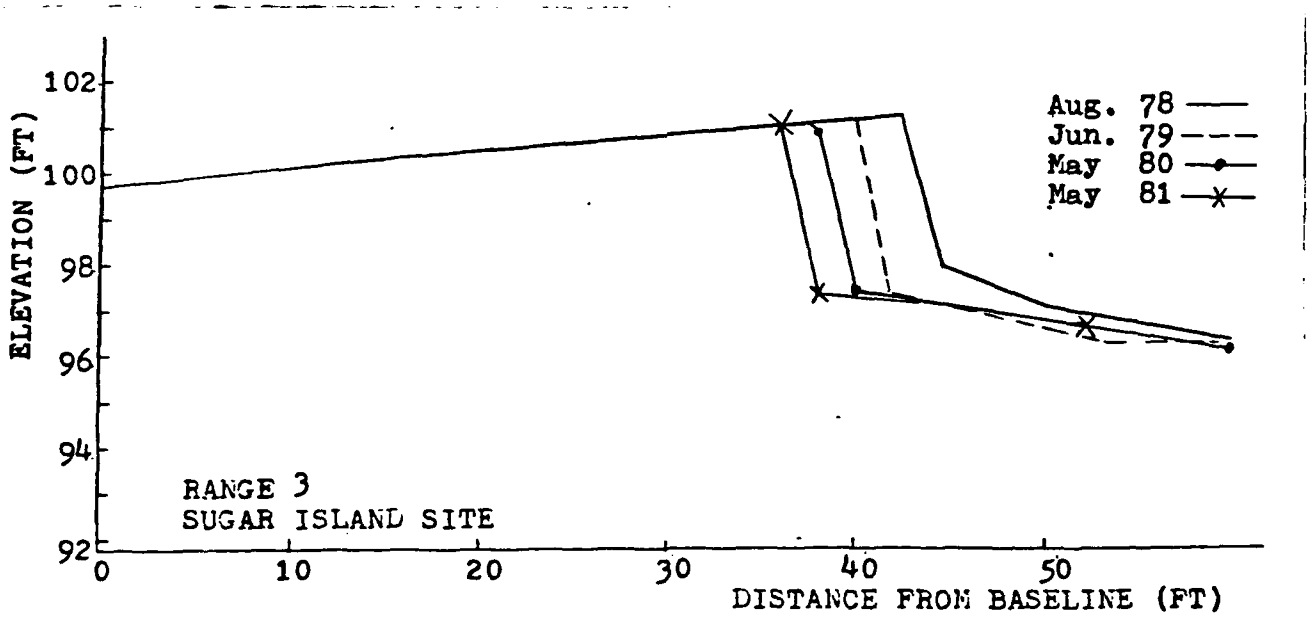

Figure 14. Range 3 Profiles.

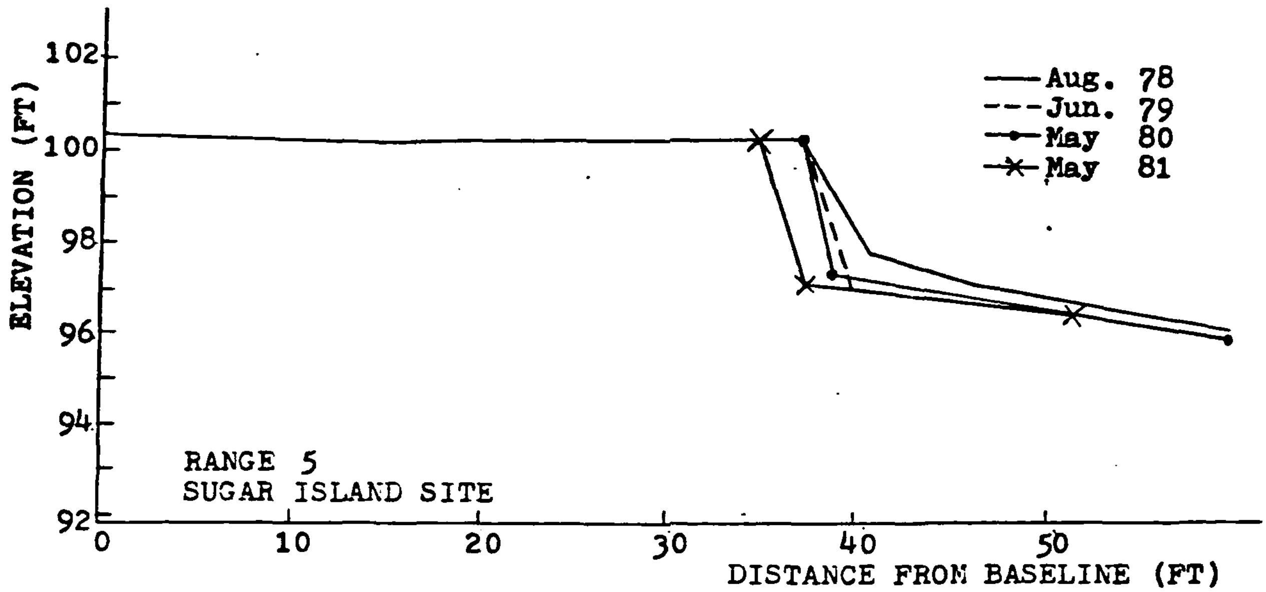

Figure 15. Range 5 Profiles.

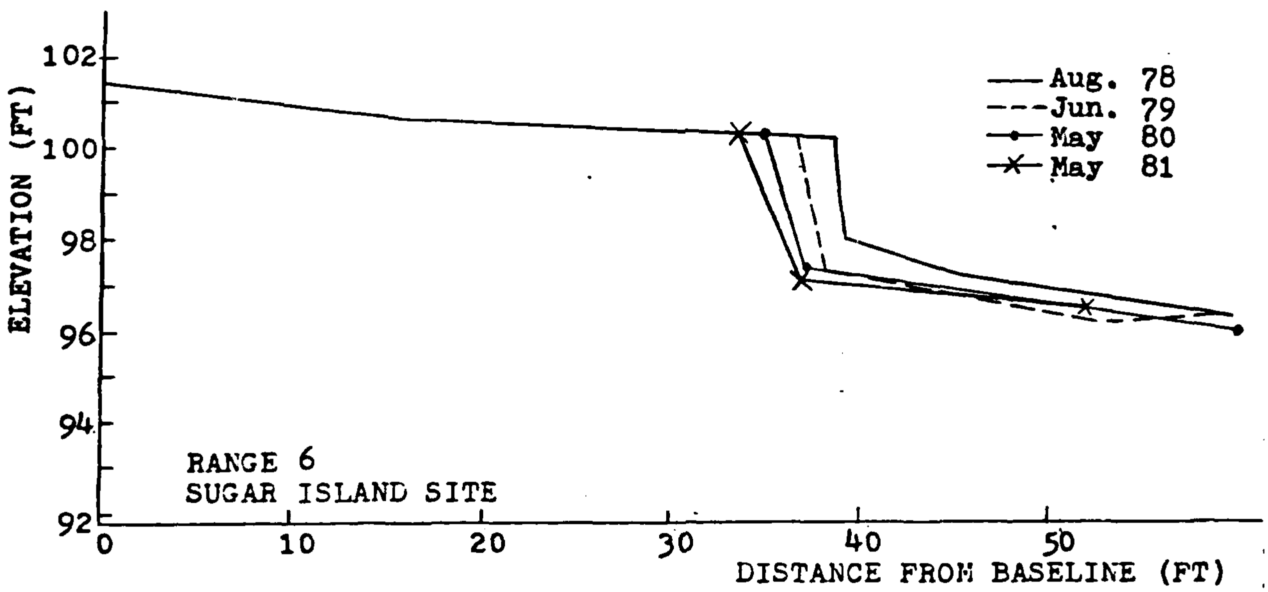

Figure 16. Range 6 Profiles.

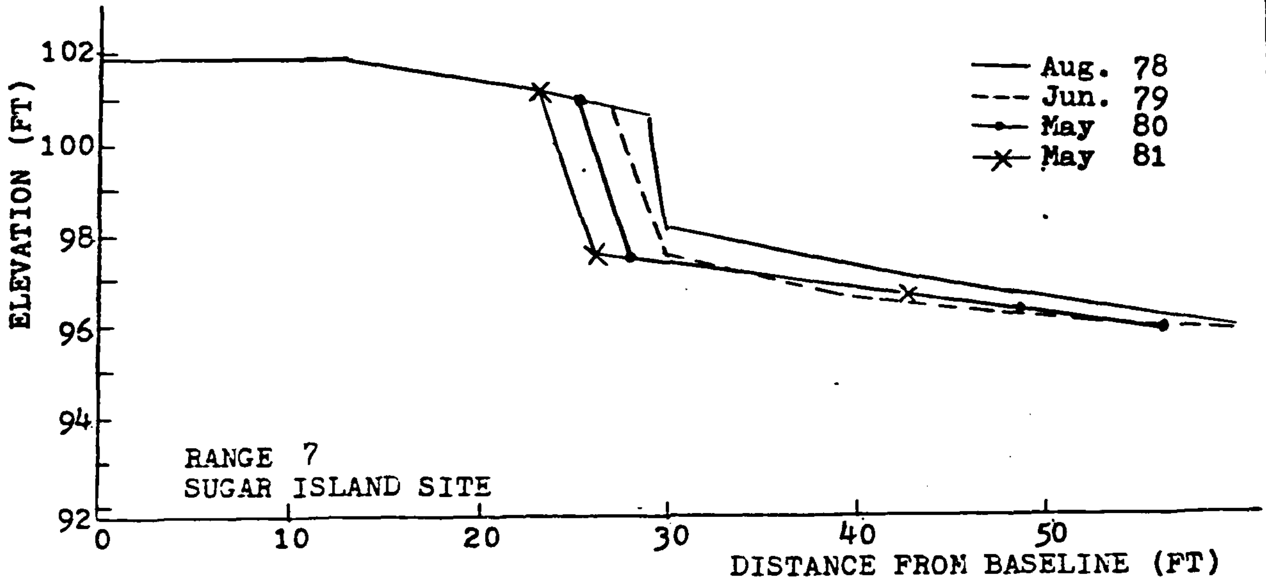

Figure 17. Range 7 Profiles.

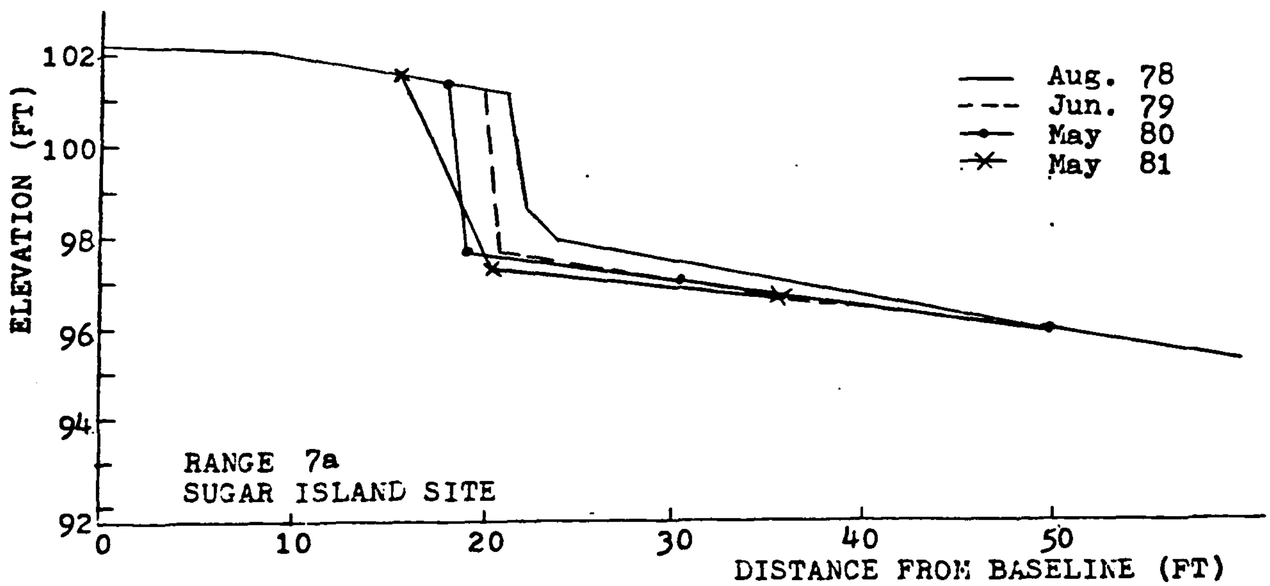

Figure 18. Range 7A Profiles.

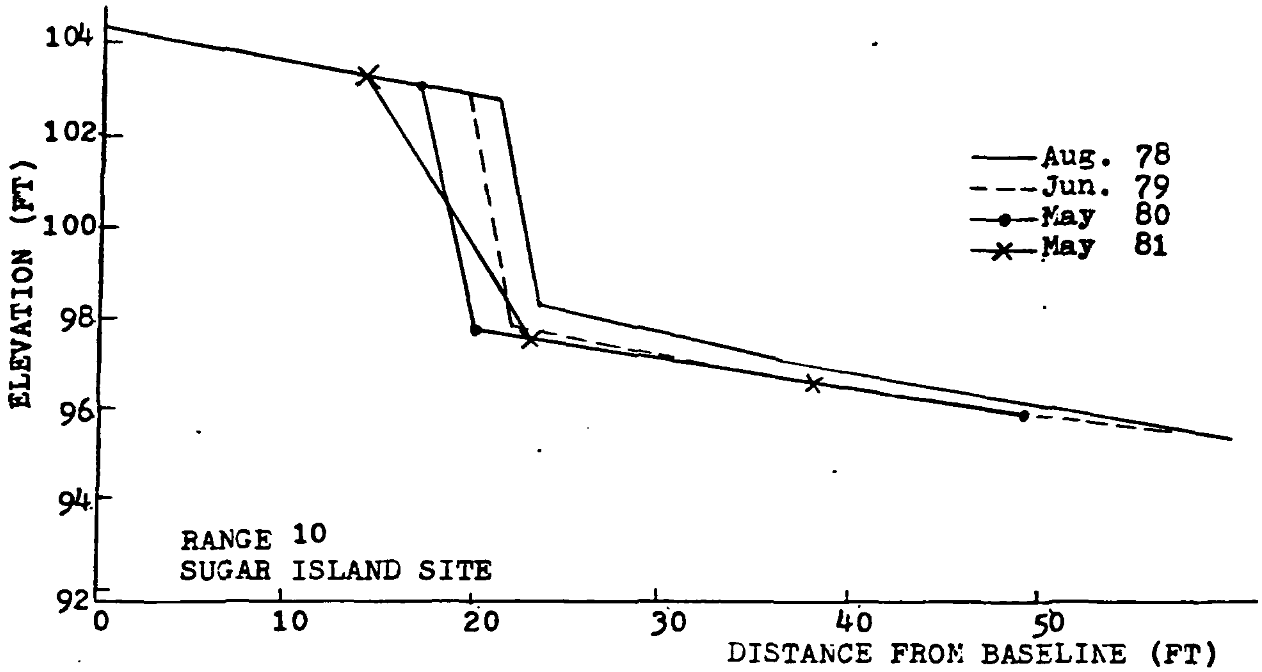

Figure 19. Range 10 Profiles.

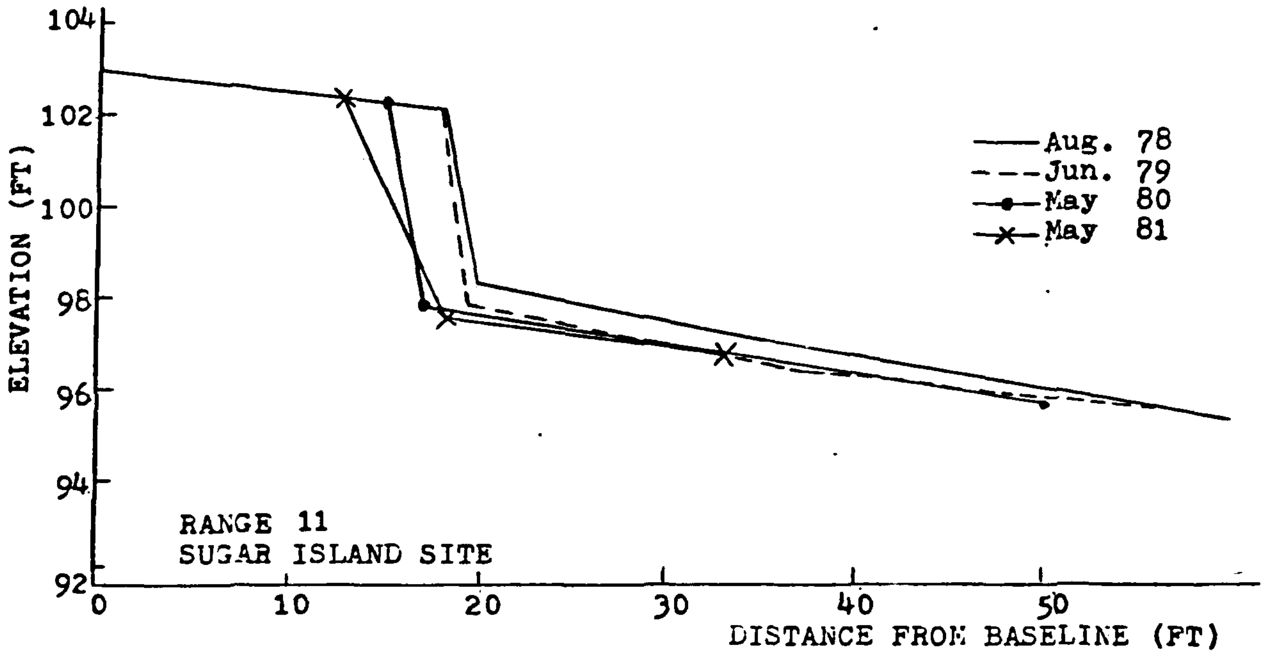

Figure 20. Range 11 Profiles.

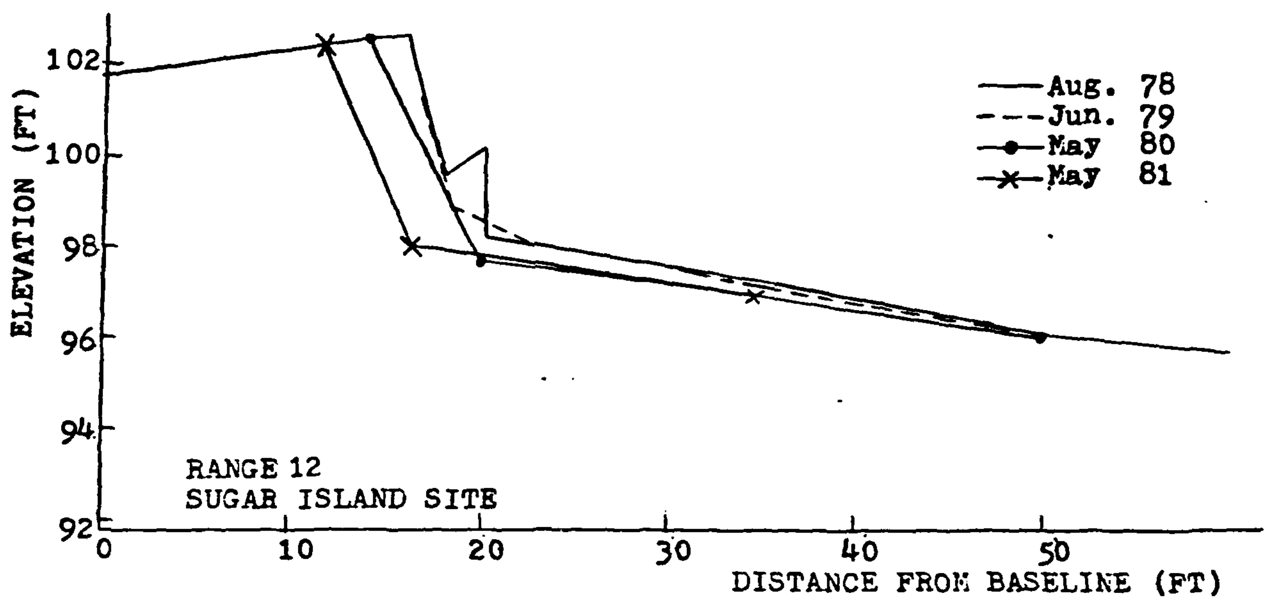

Figure 21. Range 12 Profiles.

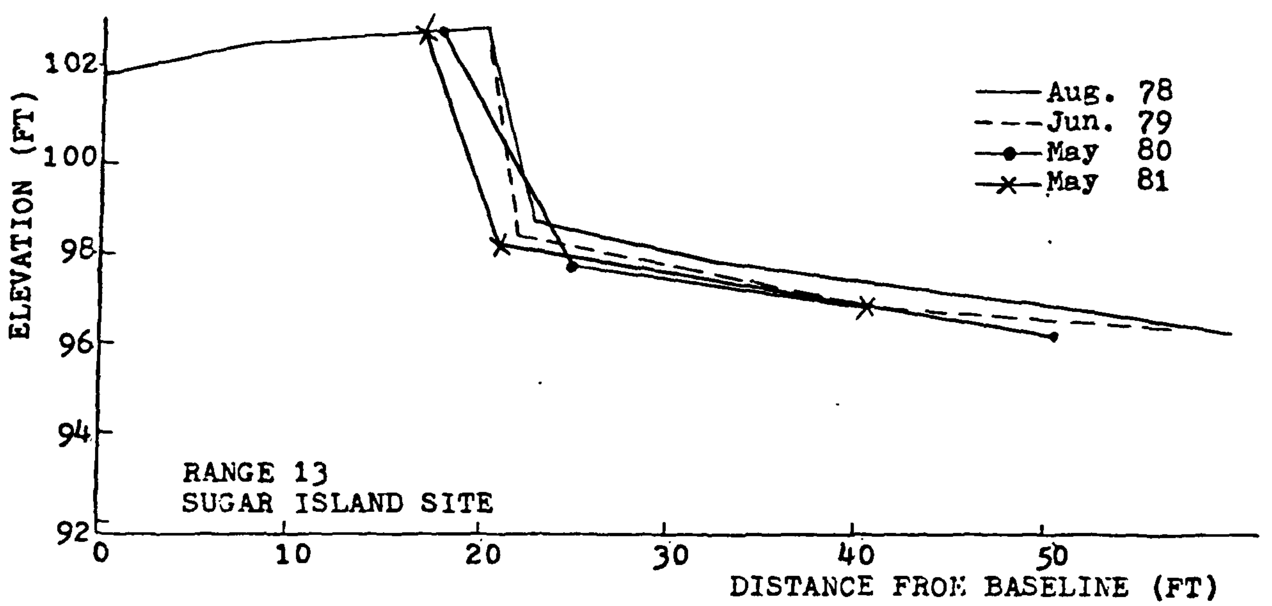

Figure 22. Range 13 Profiles.

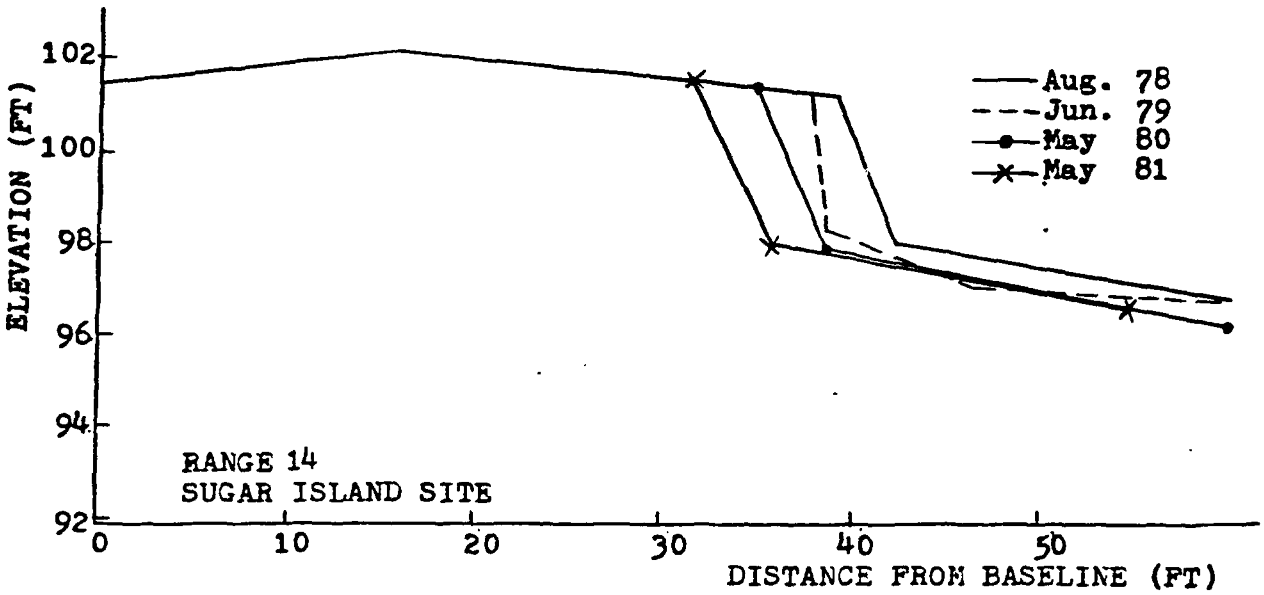

Figure 23. Range 14 Profiles.

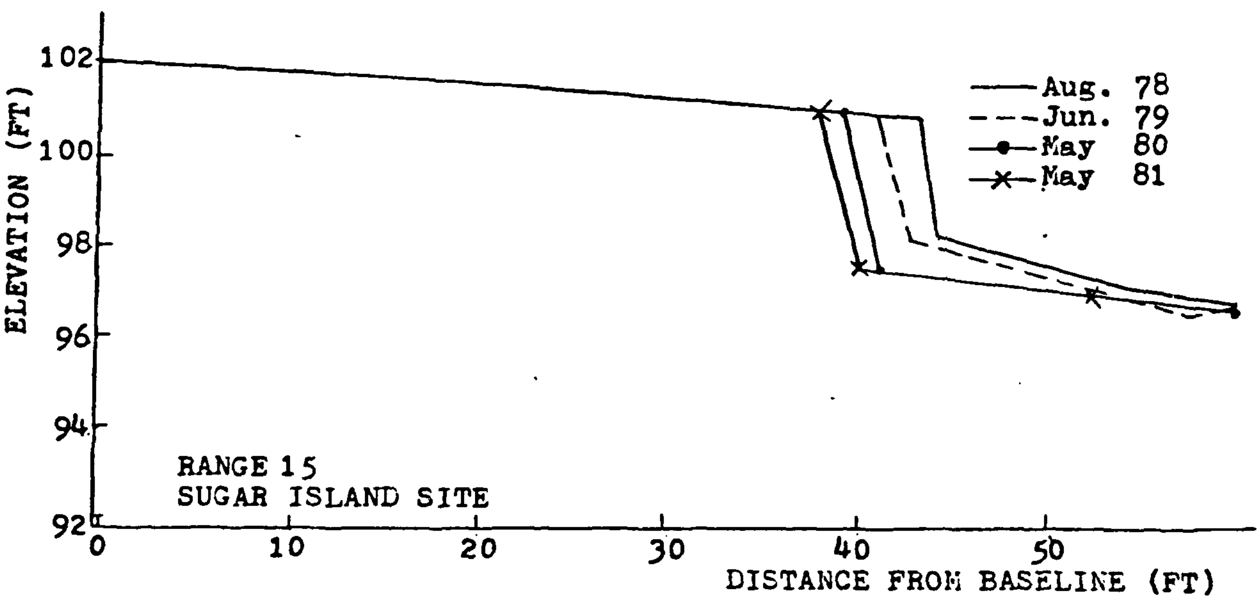

Figure 24. Range 15 Profiles.

Profiles measured under this contract at the Nine Mile Point Site were compared with those reported in previous study periods. The profile measurements reported for earlier years have shown no change except for the inshore migration of a small berm near Range 5. The results from the 1980 closed navigation season however, showed nearshore alterations at all ranges except Range 3. Range 3 is protected with rip-rap and rock pl[illegible] along the bluff and shoreline and no material nearshore alteration would be expected along this range. Ranges 1, 2, 4, 6, and 7 all showed some recession of the shore area while Range 5 indicated some filling due to the migration of the sand berm located near this range. Water levels were high during the summer of 1979 and erosive forces would have been applied at higher elevations of the shore and bluff during this period. The results of the 1980-81 season again show no significant change except that noted in the section discussing offshore bottom profiles.

The observations relative to spring breakup were conducted during the latter part of March 1981. There was no ice present at the Sugar Island Site, fast grounded shore ice for a distance of about 30 feet at the Adams Site and fast grounded shore ice for a distance of about 100 feet at the Nine Mile Site. There were no active shore cracks nor any evidence of vessel disturbance of the ice or bottom at any of the sites.

Dock Damage

Docks along the entire length of the St. Marys River have been observed for ice-related damage during periods with and without winter navigation. Emphasis during the past two closed navigation seasons was placed on structures in areas which have a high potential for navigation-related damage in the past.

Docks were first visited shortly after the close of navigation, and in some cases significant damage was evident. Since the study was to address damage during a period without navigation, the condition of the structures during the first field period were used as a basis for subsequent comparisons.

For the 1979-80 winter season no visually apparent damage occurred during the period of closed navigation to any of the structures visited. Details of that season may be found in last years report (Wuebben, 1981) including a time sequence of photographs of the various docks through the winter.

In an effort to detect damage to shore structures that was not visually apparent several docks were selected for more precise monitoring. In particular these docks were surveyed to detect vertical motion and the surrounding ice sheets were monitored for horizontal movement. Areas considered to be of primary concern included several docks along the mainland shore of Lake Nicolet in the vicinity of Six Mile Point and Neebish Island near Johnson's Point. No visually apparent damage was observed at other locations along the river.

Six Mile Point. Structures at Six Mile Point are in an area of significant damage potential due to navigation, but they are better constructed than most along the St. Marys River. The docks monitored (referred to here as A, B, and C) are shown in Figures 25 through 32. Dock C is the LaPeers Marine Gulf Station dock discussed in last years report and Docks B and A are the successive docks traveling upstream along the mainland shore. The photographs depict conditions shortly after the close of navigation.

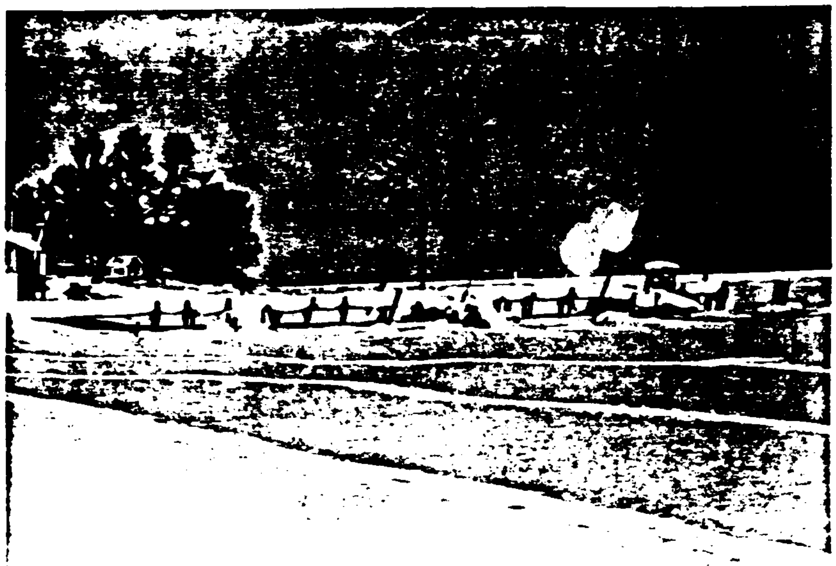

Figure 25. Dock A Overall View.

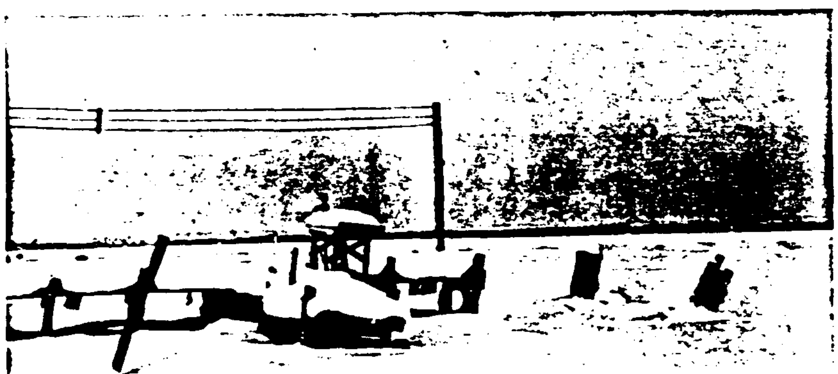

Figure 26. Dock A, Offshore End.

Figure 27. Dock A, Onshore End.

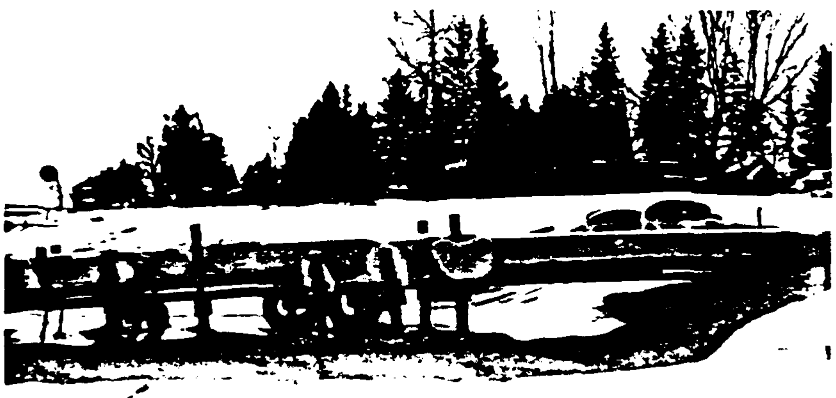

Figure 28. Dock B, Onshore End.

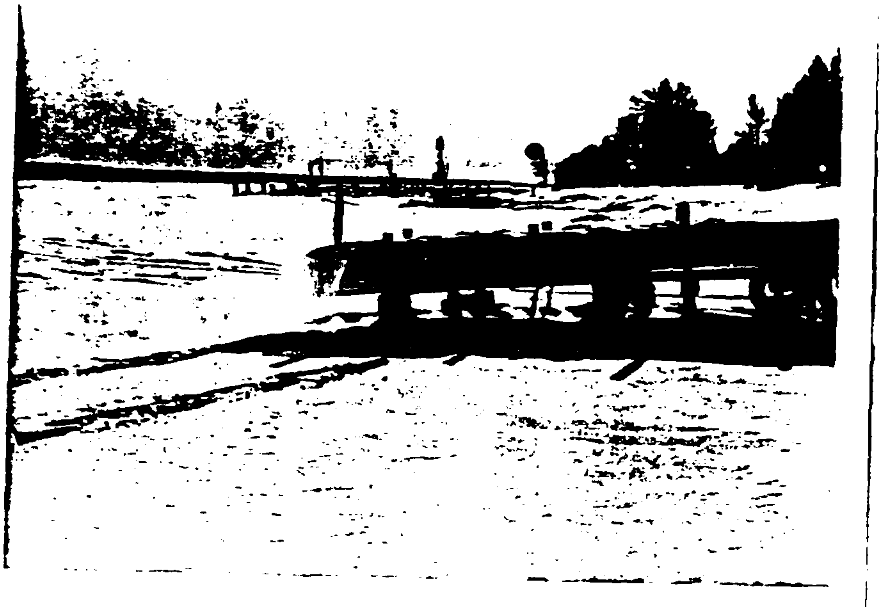

Figure 29. Dock B, Offshore End.

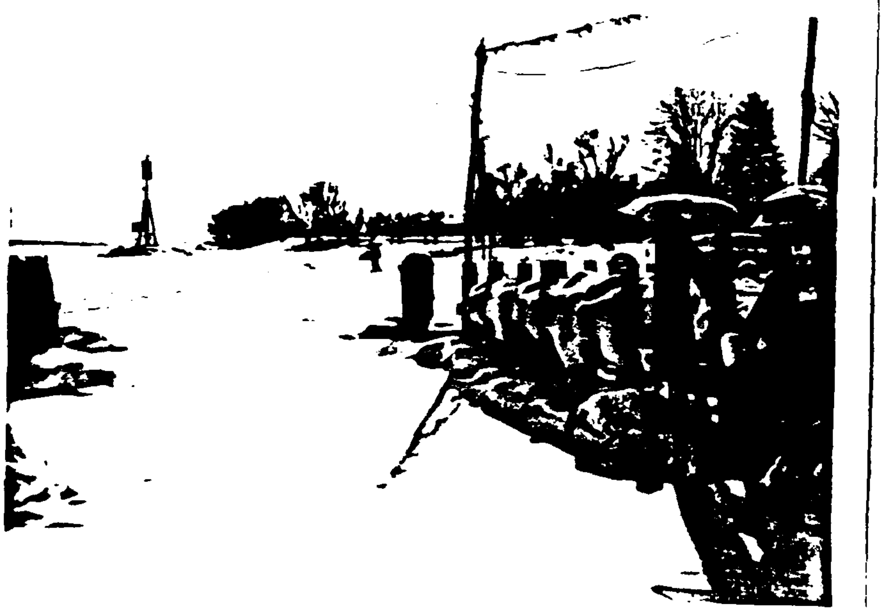

Figure 30. Dock C, Offshore End.

Figure 31. Dock C, Closeup of Offshore Finger Pier.

Figure 32. Dock C, Closeup of Finger Pier.

An examination of the photographs of Dock A in Figure 25 through 27 shows some apparent horizontal movement of the dock and surrounding piles prior to the closed navigation season. In particular, notice that the motion appears to be in the offshore direction. Such motion could be explained by the horizontal jacking of ice due to ship-induced drawdown and surge discussed earlier, but this was not documented since the movement occurred prior to initiation of this study.

During the closed navigation period, however, no horizontal movement of any of the structures or the ice cover were detected. During the first field period, pins were placed in the ice, particularly across existing cracks, but no measureable change in the relative locations of these pins was detected. The lack of movement was anticipated because the active cracks present at the close of navigation refroze during the closed navigation period.

In summary, the structures near Six Mile Point were monitored throughout the closed navigation seasons of 1979-80 and 1980-81 and no perceptible vertical on horizontal movement occurred. These structures are located in an area of significant potential damage however, and some movement of the docks apparently had occurred prior to the close of navigation.

Johnson's Point. Another site which has suffered significant damage during previous winter navigations seasons is the Little Neebish Resort just upstream from Johnson's Point on Neebish Island. Figure 33 is a photograph of the Corps of Engineers demonstration dock discussed in last years report. The photo is taken while standing on shore and this dock lies parallel to the shore. The four finger piers extending from the

demonstration dock toward shore were added by a local property owner. The demonstration dock is also shown on the left of Figure 34 with the newer finger piers extending to the right.

The Corps of Engineers demonstration dock was adequate to handle the ice forces it experienced and no significant movement was detected. The newer finger piers, however, were constructed in a manner similar to previous docks in the area and substantial movements were apparent by the close of navigation. Figure 35, taken just after the close of navigation in January, shows that the ends of all four finger piers have been vertically jacked. Note the ice collars showing previous points of contact between the ice cover and the piles. Further, as Figures 36 and 37 show the lifting of the various piles was not uniform. Such differential movements can increase damage to the deck and make restoration of the dock more difficult.

In addition to visual inspections, the elevation of several components of this structure were monitored. During the early part of the closed navigation season no additional movement of any of the piers was detected. Measurements after the nine vessel passages on the fourth and fifth of March however show that the various components of the finger piers were raised vertically from 0 to about 5 inches. No significant horizontal movement was observed.

There was some differential horizontal movement at a monitored ice crack. Pins were placed on each side of an active crack just after the close of navigation. During the closed navigation period this crack refroze and no change in the location of the pins was detected. After the

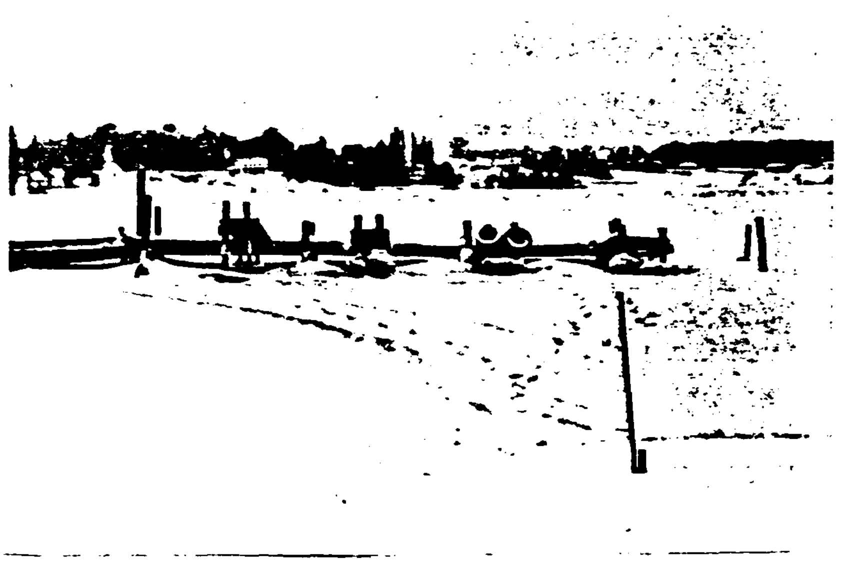

Figure 33. Overview of Demonstration Dock.

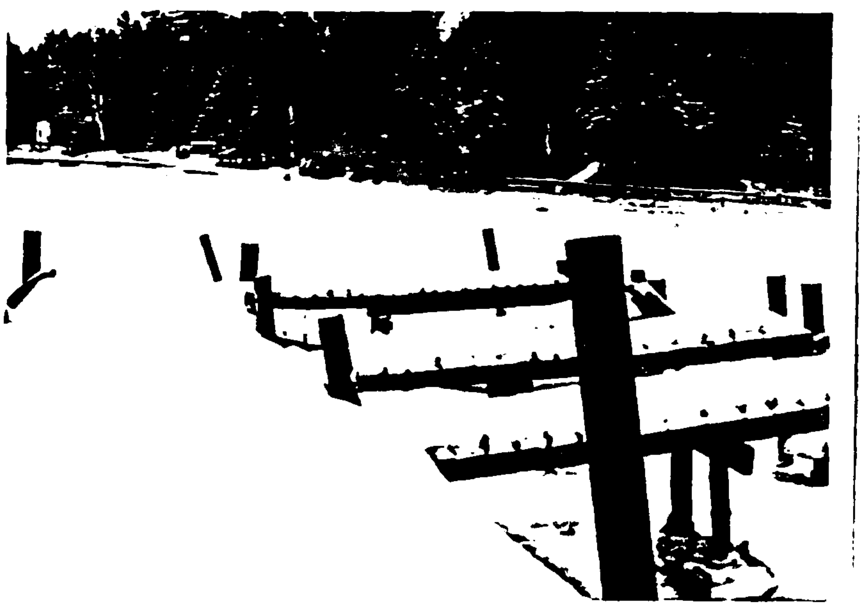

Figure 34. Demonstration Dock with Newer Finger Piers Extending to Right.

Figure 35. Jacking of Finger Pier End Piles.

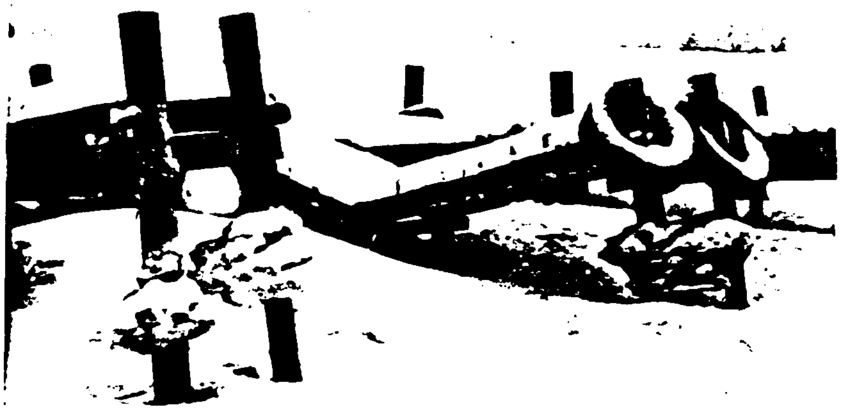

Figure 36. Differential Movement of Dock Components.

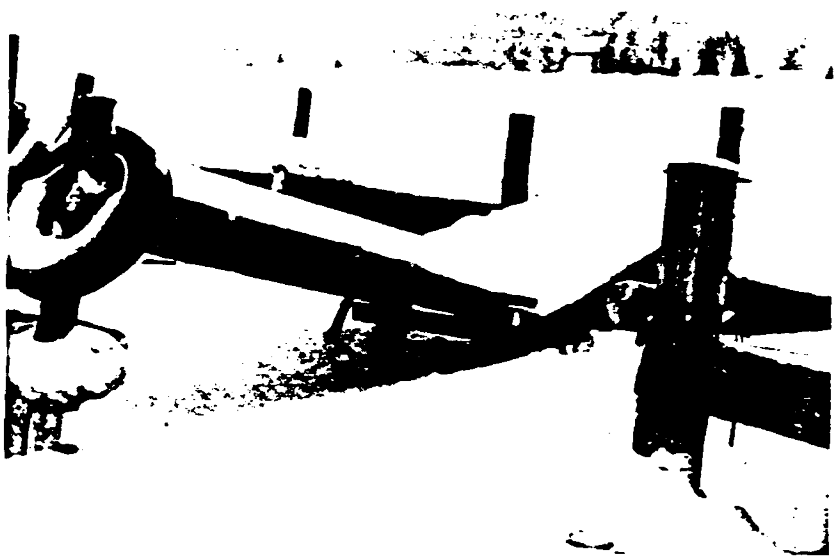

Figure 37. Closeup of Damaged Finger Pier.

nine vessel passages, the pin locations were rechecked and the crack had reopened about 1.5 inches. This small amount of movement is not significant in terms of damage for this season, but it does point out the potential significance of active cracks during periods of more frequent navigation in ice if these cracks pass through structures.

There was no measured damage during the period closed to navigation, but there was some vertical movement (up to 5 inches) of the small, lightly constructed finger piers during the nine vessel passages recorded on the 4 and 5 of March. No structural movements were observed at this site during the 1979-80 closed navigation season.

Discussion. The lack of damage to structures during the period closed to navigation is not surprising. Damage to small docks is typically due to either horizontal movement of the ice sheets or vertical jacking due to water level fluctuations. Damage due to horizontal forces can occur naturally during the unstable early ice period or during spring breakup. Typically, during the mid-winter period on the St. Marys the ice is thick, and completely covers the water in most areas of the St. Marys River so that little horizontal movement takes place. At the close of navigation for the 1980-81 winter season, nearshore ice thickness in areas of concern was already on the order of one foot.

With winter navigation, however, there can be small, incremental movement of large ice masses. With the passage of a ship the resultant tends to draw water in the offshore direction. This also pulls the ice cover slightly toward the channel. The following rise in water levels does not completely close the crack, and there can be some freezing of new ice

in the crack. With repeated cycles, this mechanism can incrementally jack the ice cover horizontally toward the channel. If any cracks pass through a structure they can be pulled offshore as well.

Another source of damage is the vertical movement of an ice sheet. On any large body of water the water level is constantly fluctuating. During periods of open water, the normal fluctuations are relatively harmless. In conjunction with an ice sheet that is firmly attached to marine structures, these fluctuations can exert large vertical forces through the floating ice cover.

Typically the structures that suffer the most damage are light duty, pile supported piers such as those found on the St. Marys River for pleasure boaters. Designed for the summers activity, the support piles have very little skin resistance to an upward force. With a rise in water level, the buoyant ice sheet lifts the pile from the soil and the void under the bottom tip of the pile fills in. When the water level again drops, the weight of the ice is supported by the skin friction and point bearing of the pile. Since the pile is not driven into the soil as easily as it is pulled out, if the water level continues to drop, the ice will eventually break and the ice sheet will drop relative to the pile. The ice may then refreeze to the pile but at a lower position now that the pile has been lifted. This process then can be repeated in cycles throughout the winter, gradually "jacking" the pile completely out of the soil.

As shown in Figure 38, hourly water level measurements for a recent January period show natural water surface fluctuations of only 0.4 feet over a period of 16 days. Water level fluctuations of this magnitude or

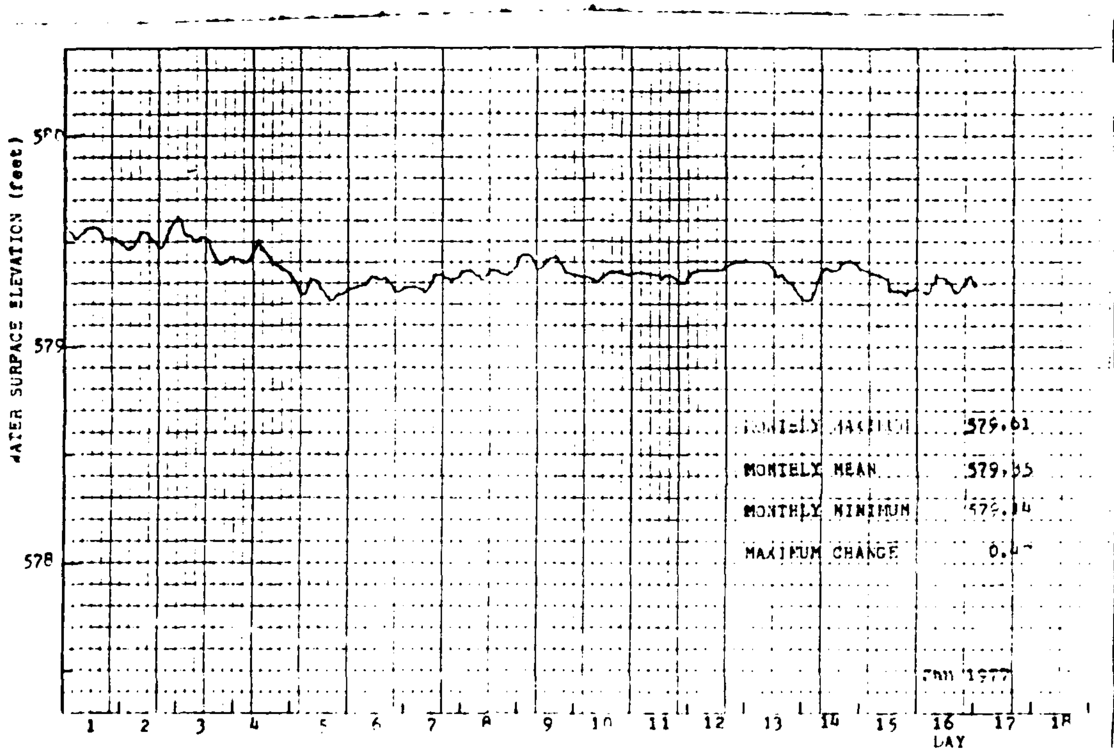

Figure 38. Hourly water level elevation, Frechette Point.

less would cause minimal if any damage to structures and in addition the fluctuation cycle frequency is low. Water level fluctuations measured during ship passages very often exceeded this level (sometimes reaching two or more feet in amplitude), and occurred as frequently as ships passed.

Figure 39 shows mean daily water level elevations at Frechette Point throughout the 1980-81 closed navigation season. The maximum variation in water levels over the entire period is about one foot, but this is a decrease of one foot which would not cause pile uplift. The maximum increase in water level was 0.6 feet occurring on 4-6 January.

CONCLUSIONS

The data and observations contained in this report suggest little if any erosional activity at most offshore locations. There would appear to be some bottom filling nearshore at the Nine Mile Site. There was some recession of the bluff recorded at the Sugar Island Site, but no significant change at the Adams Site or Nine Mile Point Site.

The active parallel cracks in the ice which were noted frequently during the years of study with winter navigation present were not observed at any of the study sites during the periods of field investigation in the winter of 1980-81.

The grounded fast shore ice present at the Adams Site and the Nine Mile Site appear to be effective during spring breakup in mitigating shoreline erosion due to the movement of broken floating ice pans.

Since winter navigation was essentially absent during this present study period and active during the periods covered by previous reports the combined evidence appears to be inadequate to factor winter navigation

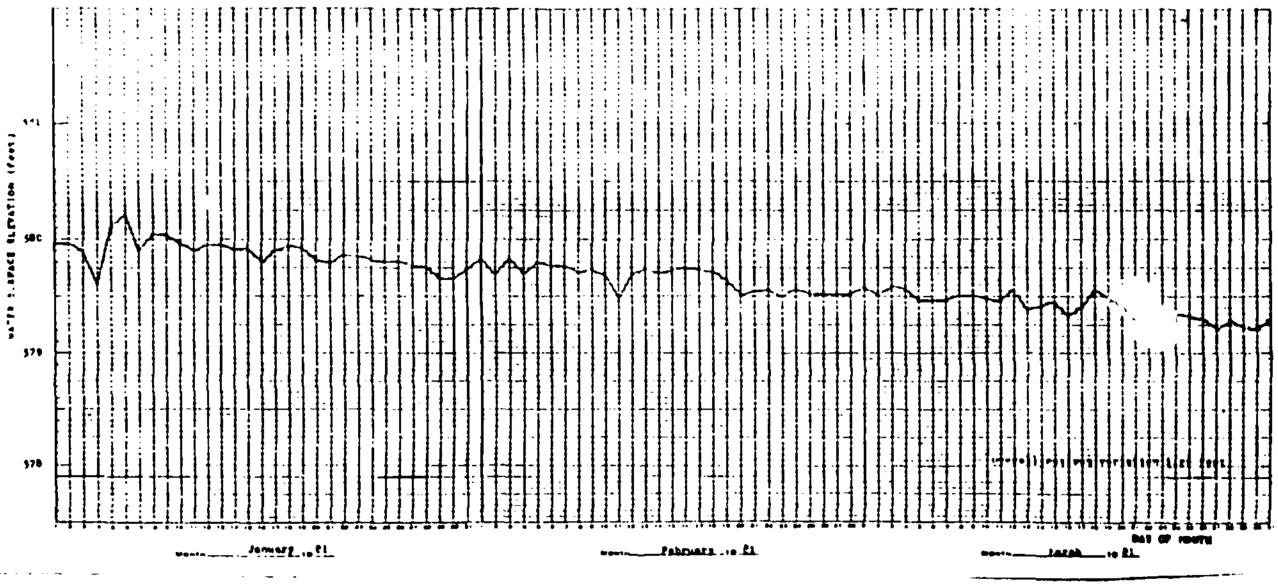

Figure 39. Frechette Point water level elevations, 1981 closed season.

effects, if any. If erosive forces are present relative to winter navigation activity, they could only be factored by a more intensive study including both summer and winter periods at a much more frequent interval. Should a future monitoring program be established, it is essential that the frequency of observations be considerably expanded.

Although some docks were found to be in a damaged condition at the beginning of the closed navigation period, none of the monitored docks appeared to have sustained damage during the period of study in which no navigation took place. There were nine vessel passages in early March and a small amount (a few inches) of pile uplift was recorded at one dock. Previous experience indicates that the greatest damage occurs when the ice thickness is from 0 to 6 inches. Since this range of ice thickness was surpassed before the close of navigation damage which occurred during this critical period could not be addressed. In addition, spring breakup occurred after navigation was resumed.

Another topic which should be studied is the effect of winter navigation on ice production. Continuing ice breaking by vessel passage with subsequent refreezing can increase the amount of ice present in the river. In addition, the horizontal jacking of the ice cover towards the channel mentioned in an earlier section can further increase the quantity of ice. This added ice can substantially effect water levels and flow velocities in the river, which in turn can affect the magnitude of vessel effects.

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